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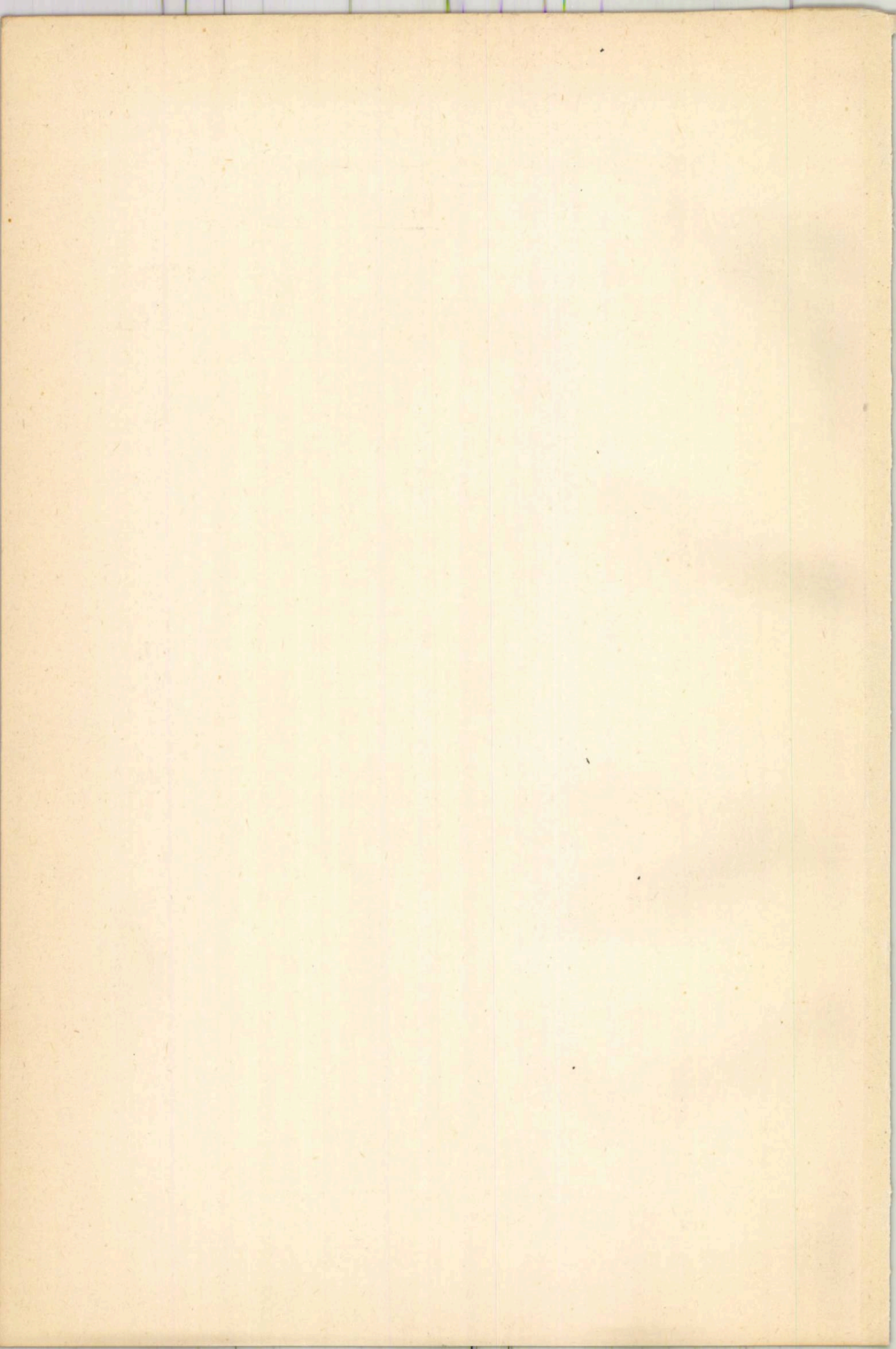
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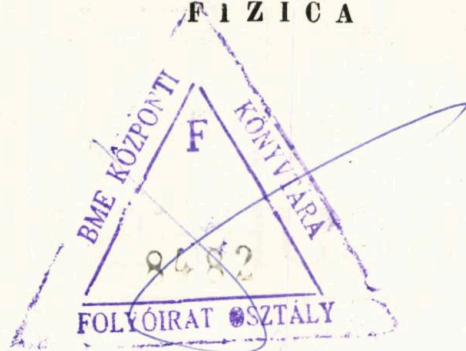


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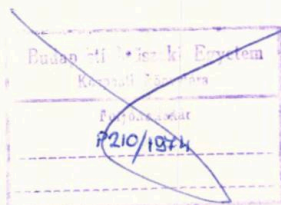
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THE CALCULATION OF THE DISTRIBUTION OF PROTONS FROM THE REACTION $n + d \rightarrow n + n + p$ FOR NEUTRONS 14 MEV

S. C. MUSCALU

By using the summation method of the nonrelativistic diagrams corresponding to the inelastic scattering of nucleons on deuterium [1], the energy spectrum of protons from the reaction $n + d \rightarrow n + n + p$ is calculated [2].

In the range in which the neutron interaction momentum $\vec{f}$ in the final state is small, and the protons are scattered under small angles, i.e. the transmitted momentum $|\vec{q}| = |\vec{K}_0 - \vec{K}|$ is small compared to $|\vec{f}|$, the differential cross section can be obtained in a relative simple form:

$$\frac{d^2\sigma}{d\Omega dW} = A(K_0, \alpha; K, f) \left| B(\vec{K}_0, \alpha; \vec{K}, \vec{f}) + iC(\vec{K}_0, \alpha; \vec{K}, \vec{f}) \right|$$

where $A(K_0, \alpha; K, f)$, $B(\vec{K}_0, \alpha; \vec{K}, \vec{f})$ and $C(\vec{K}_0, \alpha; \vec{K}, \vec{f})$ have the expression given by the relation (6) and (13) from [2].

In this case the multiple scattering is negligible, or at least its contribution is almost independent on the incident particle energy, or on the proton scattering angle θ .

The calculation of the energy distribution of protons obtained in the above mentioned reaction is carried out in the center of mass system for the scattering angles of 8° ; $17,3^\circ$; $25,7^\circ$ and $30,5^\circ$. In *fig.1* the calculated values are compared with the experimental data.

The continuous curve is calculated with the equation (1), and the stars represent the experimental values taken from [3]. There is a good agreement between the theory and experiment, especially for small scattering angles. This agreement becomes worse as the scattering angles increase, fact which confirms that the used approximation is quite good for small scattering angles and less exact at higher angles. This can be explained also as the transmitted momentum q increases with the scattering angle and approaches the values of the interaction momentum of the two neutrons obtained in the final state. In consequence the approximation used in the differential cross section calculation is no more valid.

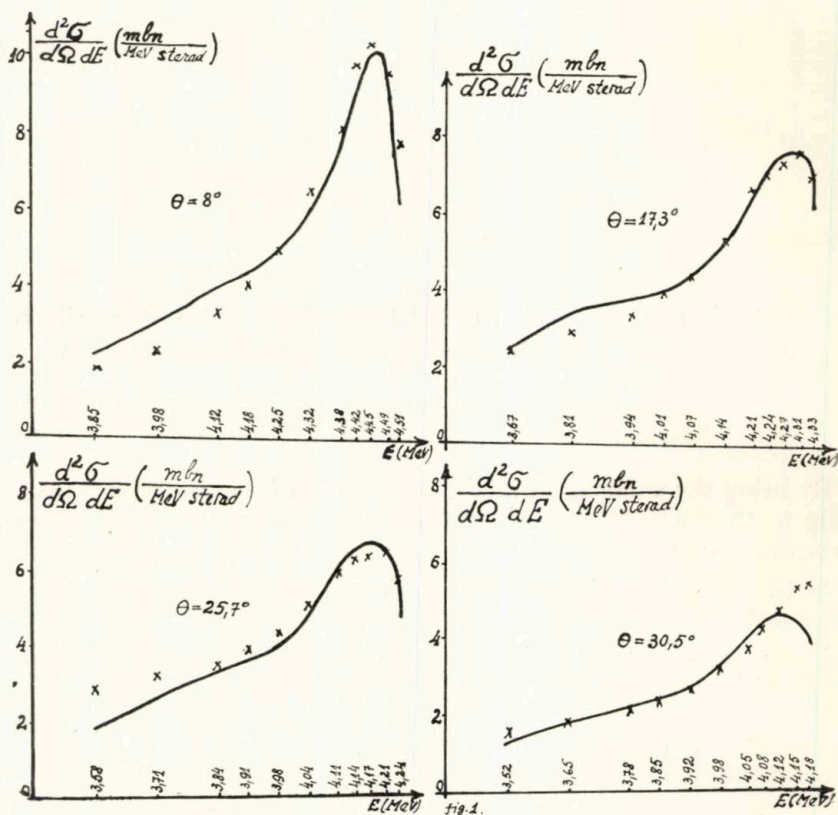


Fig. 1

The higher order diagrams who take into account multiple scattering have been neglected by supposing that their contribution can be represented by a term almost independent on the incident particle energy and on the scattering angle θ . This supposition is confirmed by the good agreement especially at the angles θ_{ic} of 8° ; 17.5° and 25.7° . This term increases slowly enough with the scattering angle, as it can be seen in fig. 2, where the angular distribution of protons is represented (the theoretical values, calculated with the formula (I), are represented by the continuous curve, and the experimental data [3] are shown by stars).

CONCLUSIONS

According to the above discussion the following conclusions can be drawn:

1) For a qualitative description of the nucleon-deuterium scattering the reaction amplitude, calculated in the momentum approximation, can

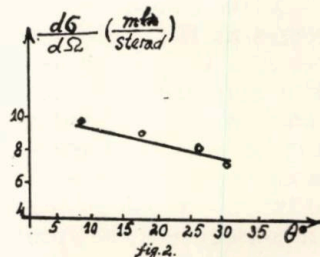


Fig. 2

be used. It represents the sum of the contribution of angular diagrams corresponding to the interaction of pair of particles in the final state and of the contribution of squared diagrams corresponding to the interaction of two particles with small f in the final state.

2) The multiple scattering can be considered, in a first approximation, as a function of incident particle energy and of the scattering angle of the particle obtained from the interaction; its contribution has a constant value.

3) The contribution of multiple squared diagrams increases with the scattering angle and decreases with the incident energy.

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THE MODIFICATION OF THE SPECTRAL STRUCTURE OF THE LIGHT BY MODULATION

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It is introduced the complex modulation function and there are established its concrete forms for some of the most usual modulation kinds and methods. On this basis, it is achieved a unitary theoretical treatment of the transformations underwent by the light by modulation: It is studied both the spectral line decomposition by modulation and the relation between the spectral structure of the modulation components and that of the initial light.

1. INTRODUCTION

By periodical modulation of an optical carrier, takes place, as in radio-technics too, the appearance of some lateral frequencies, situated on both sides of the initial frequency and differing from it by integral multiples of the modulation frequency. In optical terms, the modulations of the light has as effect a modification of its spectral structure, modification which consist of a broadening of the line or a splitting into more components, according to the fact that the modulation frequency is less or higher than the spectral width of the line.

Working at the limit of the experimental possibilities of that period, Rupp [1] proved the broadening of the green line of the thallium by Kerr modulation with amortized oscillations with a frequency of 10^8 Hz., by the help of a laborious and refined method, in 1928.

The problem is considered again in 1962, by P. Connes, Duong Hong Tuan and J. P i n a r d [2], who achieved the decomposition in group, by Kerr modulation, of the „artificial lines“ produced by a resonance cavity of laser type; the width of these artificial lines being much less than the width of the

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finest natural lines which can be produced by the classical sources, that is of 1 MHz. order, the splitting could be observed at relative low modulating frequency, of 10 MHz. order. In the same paper it is shown that the usage of some Kerr cells in convenient arrangements, makes possible to impose to the light any of the modulation kinds known in radiotechnics. After the development of the light modulation technics in ultra-high frequency [3], K a m i n o w [4] makes the most direct prove of decomposition by splitting of the Fabry-Perot rings of a He-Ne laser light, as a result of its electro-optical phase modulation, at a frequency of 9 GHz. order. The different frequencies which appear by modulation are coherent one with another [2]. This fact let F i s c h e r [5] make the evidence of the light spectral decomposition by modulation at much less frequencies than the spectral line width, on the basis of the photographic recording of the moving fringes which arise by interference of these different frequencies.

In the present paper we shall introduce a theoretical unitary formalism, in the frame of which we shall establish some general results regarding the spectral structure transformation of the light by modulation. These results will be exemplified and discussed respective to some of the most usual modulation types and methods.

2. THE MODULATION FUNCTION AND ITS SPECTRAL DEVELOPMENT. THE ACTION OF THE MODULATION ON A MONOCHROMATE

All types (A.M., P.M., F.M., S.S.M.) and technics of light modulation (mechanical, electro-optical, magneto-optical) can be theoretically unitarily treated on the basis of a *complex modulation function*, whose concrete expression is established for each of this cases in part.

We define this function by the transformation which is operated by the modulator on a received monochromate:

$$M(t, \omega) = \frac{V_{\omega}(t)}{U_{\omega}(t)} \quad (1)$$

where $U_{\omega}(t) = a_{\omega}e^{-i\omega t}$ is ω monochromate, $V_{\omega}(t)$ is its corresponding output disturbance, and the modulation function depends, generally, on the frequency of the modulated monochromate, generally has dispersion:

$$\frac{dM(t, \omega)}{d\omega} \neq 0$$

due to the dispersion of Kerr or Verdet constants, which appear in its expression.

Irrespective of the form, of physical interest, of the modulation function, if it is periodical, of $T = \frac{2\pi}{\Omega}$ period, it can be developed into a Fourier series:

$$M(t, \omega) = \sum_{n=-\infty}^{\infty} C_n \omega e^{-in\Omega t} \quad (2)$$

with

$$C_n(\omega) = \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} M(t, \omega) e^{in\Omega t} dt, \quad (3)$$

being always noticeable only several coefficients of small index.

With (1) and (2), the action of modulation on a monochromate consist of its splitting into a series of monochromates simetrically situated on the frequency scale, towards the initial one at distances entire multiples of the modulation frequency:

$$V_\omega(t) = \sum C_n(\omega) e^{-i(\omega+n\Omega)t} \quad (4)$$

The amplitudes and the phase shifts at the origin, of the monochromates resulted by modulation, towards that received by the modulator, are given by the modules and respectively the arguments of the corresponding coefficients of the modulation function and generally differ from a carrier frequency to another:

$$\frac{dc_n(\omega)}{d\omega} \neq 0 \quad (5)$$

due to the dispersion of the modulation function.

We shall further give several *examples of modulation functions and their corresponding spectral developments*:

2.1. Mecanical Amplitude Modulation by the toothed wheel method.

If the tooth and the intertooth widths are equal and much more than the slit-source width, it is achieved a modulation of amplitude with practical rectangular profile [5] (fig. 1):

$$M(t) = \begin{cases} 0 & \text{for } t \in \left[-\frac{T}{2}, -\frac{T}{4}\right); \left(\frac{T}{4}, \frac{T}{2}\right] \\ 1 & \text{for } t \in \left[-\frac{T}{4}, \frac{T}{4}\right] \end{cases} \quad (6)$$

The Fourier coefficients (3) of the spectral development (2) of such a modulation function (Fischer chopping function) are:

$$C_n = \frac{1}{T} \int_{-\frac{T}{4}}^{\frac{T}{4}} e^{in\Omega t} dt = \frac{\sin n \frac{\pi}{2}}{n\pi}$$

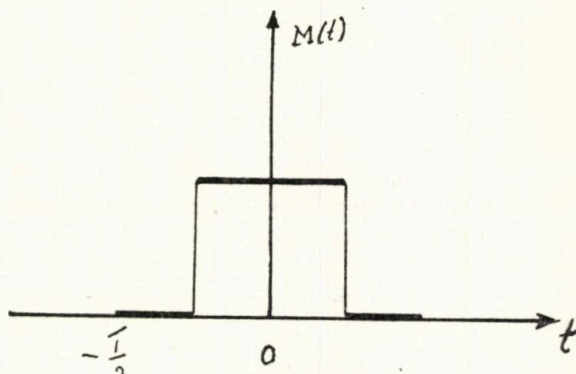


Fig. 1

so that, with (2):

$$M(t) = \sum \frac{\sin n \frac{\pi}{2}}{n\pi} \cdot e^{-in\Omega t}$$

The spectrum of this function

$$C_0 = \frac{1}{2}, \quad C_{\pm 2k} = 0, \quad C_{\pm(2k+1)} = (-1)^k \cdot \frac{1}{(2k+1)\pi} \quad (7)$$

is represented in fig.2. On the figure there are also indicated the phase relations between different Fourier components of the modulation function.

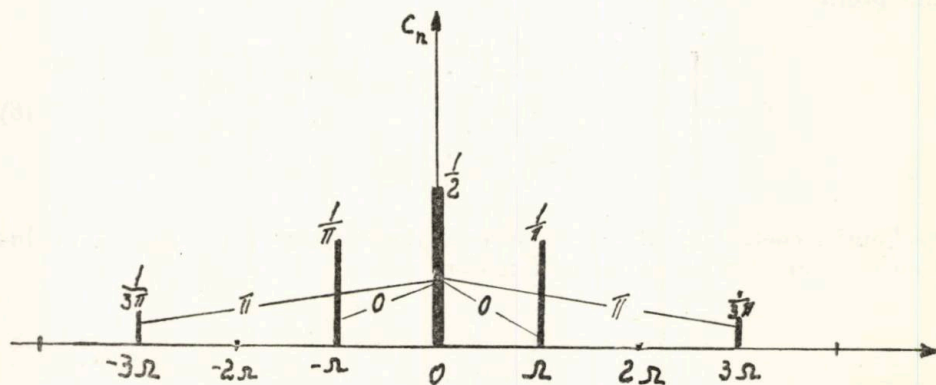


Fig. 2

As a result of modulation, the amplitude of the initial monochromate is reduced to a half and it appears a series of laterale frequencies, whose amplitudes decrease monotonously as they are situated at a greather distance from the central component. There are only odd order lateral frequencies; those of 1,5... order are in phase, and those of 3,7,... order are in opposition to the central monochromate. Apart from a complex factor, the same for all the terms:

$$V(t) = \frac{1}{2} e^{-i\omega t} + \frac{1}{\pi} e^{-i(\omega+\Omega)t} + \frac{1}{\pi} e^{-i(\omega-\Omega)t} - \frac{1}{3\pi} e^{-i(\omega+3\Omega)t} - \frac{1}{3\pi} e^{-i(\omega-3\Omega)t} + \dots \quad (8)$$

2.2. Electro-Optical Phase Modulation

It was achieved for the first time by Connes and the collaborators [2] with a nitrobenzen Kerr cell: The light sent in the cell is polarised in the direction of one of its neutral lines (fig. 3).

a) — If the vibration of the wave electric vector is on the x direction, the wave is extraordinary and, when the field is applied, its corresponding refractive index, n_e , differs from the refractive index in the absence of the field, by the formula:

$$n_e - n = \frac{2}{3} B \lambda E^2$$

For a steady electrical field applied to the cell, the output phase of the wave is in a constant retardation to the output phase in the absence of the field. If, in addition to the constant field, E_0 , a variable one is applied, for example a sinusoidal one

$$E_v = E_m \cos \Omega t$$

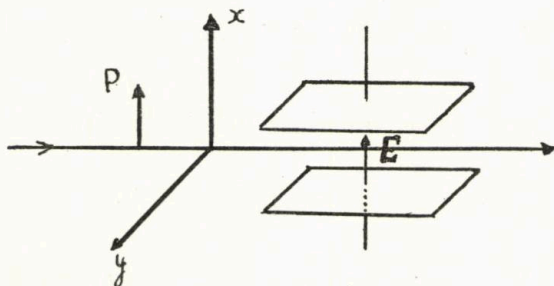


Fig. 3

the output phase will be time variable:

$$\delta_x = \frac{2\pi}{\lambda} (n - n_e) L = -\frac{4\pi}{3} BLE_0^2 - \frac{8\pi}{3} BLE_0 E_m \cos \Omega t \quad (9)$$

if $E_m \ll E_0$.

By noting

$$-\frac{4\pi}{3} BLE_0^2 = \Phi_e \quad (10)$$

$$\frac{4\pi}{3} BLE_0 E_m = m \quad (11)$$

it may be written:

$$\delta_x = \Phi_e - 2m \cos \Omega t$$

the output phase is time variable, in the first approximation in tune with the signal.

The modulation operated by the cell being, in this case, only a phase one, the module of the modulation function is constant, and the argument varies in tune with the signal:

$$M_{P.E.O.}(t) = e^{-i[\Phi_e - 2m \cos \Omega t]} \quad (12)$$

Its Fourier coefficients (3) are:

$$c_n = \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} e^{-i[\Phi_e - 2m \cos \Omega t]} \cdot e^{in\Omega t} dt = e^{-i\Phi_e} \left[\frac{1}{2\pi} \int_{-\pi}^{\pi} e^{i \cdot 2m \cos \theta} \cdot e^{in\theta} d\theta \right]$$

with $\theta = \Omega \cdot t$. The parenthesis is, up to a i^n factor, the integral representation of the n - order first kind Bessel function, so that:

$$c_n = i^n J_n(2m) \cdot e^{-i\Phi_e} \quad (13)$$

and the spectral development of the modulation function is:

$$M_{P.E.O.}(t) = e^{-i\Phi_e} \sum_{n=-\infty}^{\infty} J_n(2m) e^{in\frac{\pi}{2}} \cdot e^{-in\Omega t} \quad (14)$$

Or, for working with Bessel functions only of positive order:

$$\begin{aligned} \sum_{n < 0} i^n J_n(2m) e^{-in\Omega t} &= \sum_{n < 0} i^{-n} J_{-n}(2m) e^{in\Omega t} = \\ &= \sum_{n > 0} \frac{1}{i^n} (-1)^n J_n(2m) e^{in\Omega t} = \sum_{n > 0} i^n J_n(2m) e^{in\Omega t} \end{aligned}$$

and :

$$M_{P.E.O.}(t) = e^{-i\Phi_e} \left[J_0(2m) + \sum_{n>0} J_n(2m) e^{in\frac{\pi}{2}} \cdot e^{-in\Omega t} + \sum_{n>0} J_n(2m) e^{in\frac{\pi}{4}} \cdot e^{iu\Omega t} \right] \quad (15)$$

The modulation function spectrum is represented in fig. 4. The phase relations indicated on the figure between its different Fourier components,

are those conditioned only by the factor $e^{in\frac{\pi}{2}}$. A sign difference between the Bessel functions values corresponding to two such components — what is possible for $2m > 2,4$ the first zero of $J_0(2m)$ function — modifies, of course, with π , the phase relation between these components, in comparison with that dictated by the factor $e^{in\frac{\pi}{2}}$; there were not obtained, up to present, such great values of m .

With (1) and (15), apart from a complex factor :

$$V_{E.O.}(t) = J_0(2m) e^{-i\Phi_e} \cdot e^{-i\omega t} + \sum_{n>0} \left[J_n(2m) e^{-i\Phi_e} \cdot e^{in\frac{\pi}{2}} \cdot e^{-i(\omega+n\Omega)t} + J_n(2m) e^{-i\Phi_e} \cdot e^{in\frac{\pi}{2}} \cdot e^{-i(\omega-n\Omega)t} \right] \quad (16)$$

The modulated disturbance has a component with the incident frequency and a series of components situated symmetrically towards the first in the frequency scale, at distances entire multiples of modulation frequency. There are both even and odd components. The same order components are in phase. Towards the central component, the first order components are retarded with $\pi/2$, those of the second order are in opposition, those of the third order are retarded with $3\pi/2$, and only those of the fourth order are in phase.

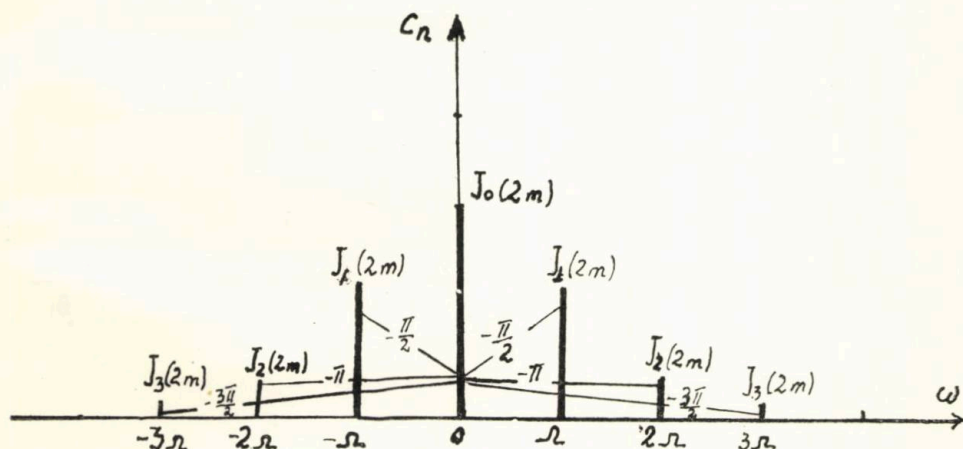


Fig 4

TABLE Nr 1.

β	$J_0(\beta)$	$J_1(\beta)$	$J_2(\beta)$	$J_3(\beta)$	$\beta(J_4)$
0	1.0000	0	0	0	0
0.1	0.9975	0.0499	0.0012	0.0000	0.0000
0.2	0.9900	0.0995	0.0050	0.0002	0.0000
0.3	0.9776	0.1483	0.0112	0.0006	0.0000
0.4	0.9604	0.1960	0.0197	0.0013	0.0001
0.5	0.9385	0.2423	0.0306	0.0026	0.0002
0.6	0.9120	0.2867	0.0437	0.0044	0.0003
0.7	0.8812	0.3290	0.0589	0.0069	0.0006
0.8	0.8463	0.3688	0.0758	0.0102	0.0010
0.9	0.8075	0.4059	0.0946	0.0144	0.0016
1	0.7652	0.4401	0.1149	0.0196	0.0025
1.2	0.6711	0.4983	0.1593	0.0329	0.0050
1.4	0.5669	0.5419	0.2073	0.0505	0.0091
1.6	0.4554	0.5699	0.2570	0.0725	0.0150
1.8	0.3400	0.5815	0.3061	0.0988	0.0232
2	0.2239	0.5767	0.3528	0.1298	0.0340

As it is seen from table I (the values of Bessel functions of first kind, up to the fourth order) and fig. 5 (the graphics of this functions, up to the second order), for values not too great of $2m$ (let's say $2m = \beta < 0.8$), together with the Bessel functions of corresponding order, the $n > 1$ order side components amplitudes have very small values as compared to that of the monochromate incident at the modulator, and the central component amplitude does not differ too much from that of the incident monochromate. For instance,

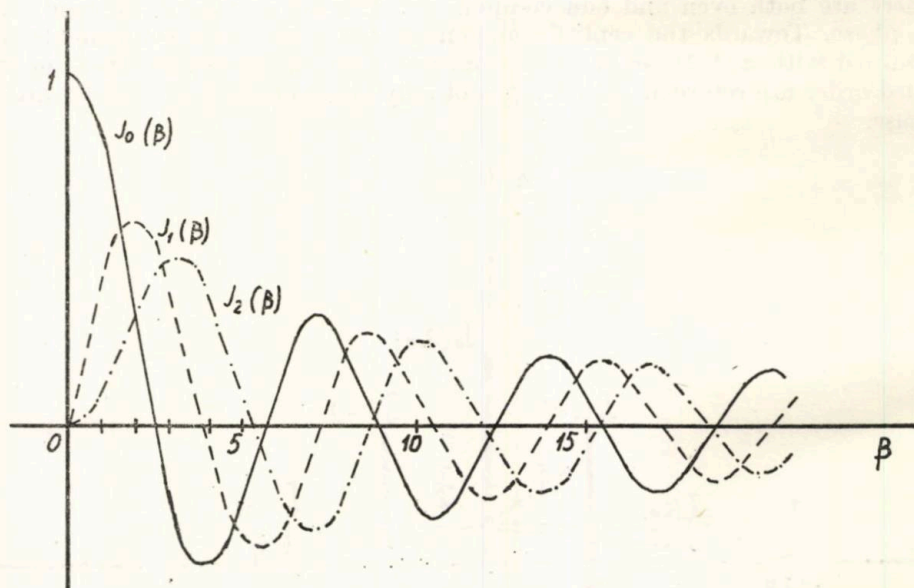


Fig. 5

for $m = 0.4$ (under Connes working conditions: $L = 5 \text{ cm}$; $E_0 = 15\,000 \frac{\text{V}}{\text{cm}}$; $E_m = 2500 \frac{\text{V}}{\text{cm}}$; $B = 5.5 \times 10^{-10} \frac{\text{cm}}{\text{V}^2}$; nitrobenzen; $m \approx 0.38$), $J_0(2m) = 0.8463$; $J_1(2m) = 0.3688$; $J_2(2m) = 0.0758$; the second order side components amplitudes are 7.6%, while the central component amplitude is 85%, from that of the initial line. In comparison to the latter, only the first order components are appreciable.

b) If the electric vector vibration is on y direction the wave is ordinary in the cell; when applying a field, E , the index varies with

$$n_0 - n = -\frac{1}{3} B \lambda E^2$$

and if this field has a constant term, E_0 , and a sinusoidal variable one $E_v = E_m \cos \Omega t$, for $E_m \ll E_0$ the out phase has the expression:

$$\delta_y = \Phi_0 + m \cos \Omega t \quad (17)$$

with (11) and

$$\Phi_0 = \frac{2\pi}{3} B L E_0^2 \quad (18)$$

The modulation function:

$$M_{P.O.} = e^{-i[\Phi_0 + m \cos \Omega t]} \quad (19)$$

has the Fourier coefficients:

$$\begin{aligned} C_n &= \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} e^{-i[\Phi_0 + m \cos \Omega t]} \cdot e^{in\Omega t} dt = \\ &= e^{-i\Phi_0} \left[\frac{1}{2\pi} \int_{-\pi}^{\pi} e^{-i \cdot m \cos \theta} \cdot e^{in\theta} d\theta \right] = e^{-i\Phi_0} \cdot i^n J_n(-m) \end{aligned}$$

But

$$J_n(-m) = (-1)^n J_n(m)$$

$$i^n J_n(-m) = (-i)^n J_n(m) = e^{-in\frac{\pi}{2}} J_n(m)$$

so that the spectral development of the modulation function is:

$$\begin{aligned} M_{P.O.}(t) &= e^{-i\Phi_0} \sum_{n=-\infty}^{\infty} J_n(m) e^{-in\frac{\pi}{2}} \cdot e^{-in\Omega t} = \\ &= e^{-i\Phi_0} \left[J_0(m) + \sum_{n>0} J_n(m) \cdot e^{-i\frac{\pi}{2}} \cdot e^{-in\Omega t} + \sum_{n>0} J_n(m) \cdot e^{-in\frac{\pi}{2}} \cdot e^{in\Omega t} \right] \quad (20) \end{aligned}$$



In fig. 6 is represented the spectrum of this function; the remark was made in connection with the phase relations between the Fourier components of the $M_{P.E.O.}$ remains valid here too.

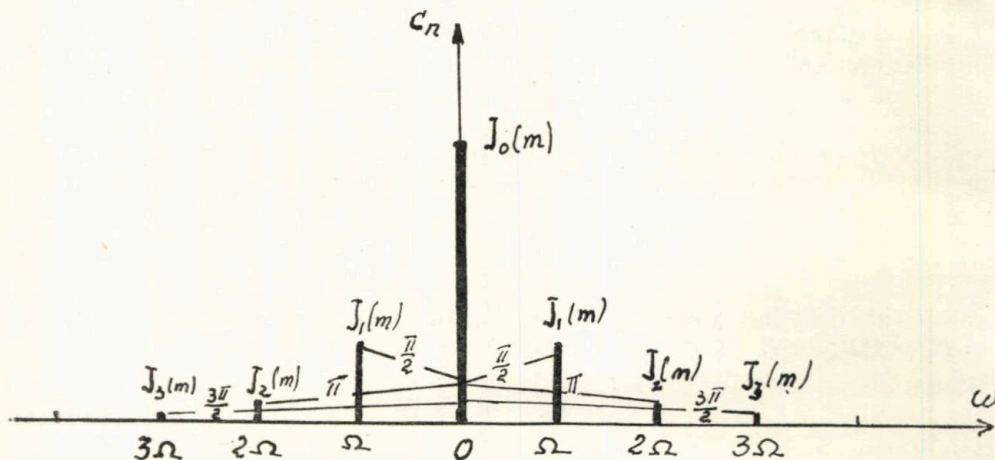


Fig. 6

With (1) and (20)

$$V_0(t)_+ = J_0(m) \cdot e^{-i\Phi_0} \cdot e^{-i\omega t} + \sum_{n>0} \left[J_n(m) \cdot e^{-i\Phi_0} \cdot e^{-in\frac{\pi}{2}} \cdot e^{-i(\omega+n\Omega)t} + \right. \\ \left. + J_n(m) \cdot e^{-i\Phi_0} \cdot e^{-in\frac{\pi}{2}} \cdot e^{-i(\omega-n\Omega)t} \right] \quad (21)$$

The action of the modulation on the incident monochromate find expression in the splitting of this monochromate. The lateral components are both of even and odd order. If in the case of phase modulation of the light extraordinary in the cell, the components of $\pm(n+1)$ order were retarded with $\pi/2$ towards the $\pm n$ order components, in this case the phase relation between them is an advance of the first ones towards the second ones (under the reserve of the reminded remark). Finally we remark the fact that, for identical conditions, the phase modulation of the extraordinary (in the cell) light has more pronounced spectral effects than those of the phase modulation of the ordinary light, the argument of Bessel functions which determine the lateral components amplitudes being double in the first case.

2.3. Electro-Optical Amplitude Modulation.

In fig. 7, we present the arrangement proposed by Connes for achieving the electrical amplitude modulation: At two identical Kerr cells

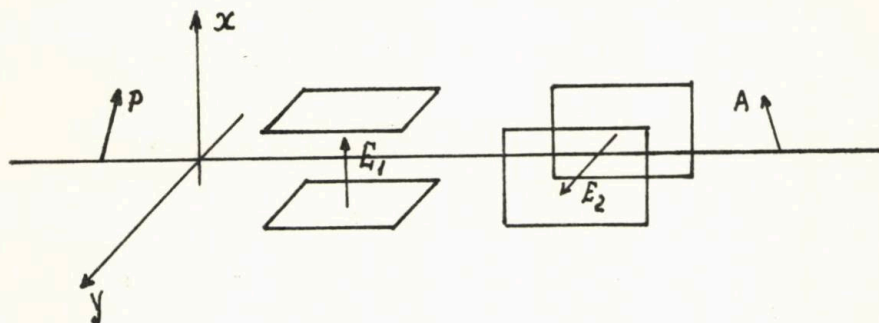


Fig. 7

disposed one after the other with the plate planes respectively perpendicular, are applied the fields:

$$E_1 = E_0 + E_m \cos \Omega t$$

$$E_2 = E_0 - E_m \cos \Omega t$$

(the constant terms — identical, the harmonical ones having identical amplitudes, in opposition). The cells are mounted between crossed or parallel polarizer and analyzer fixed at 45° towards the fields directions. The x component of the incident polarized light (the electric field vector oriented on x direction) is extraordinary in the first cell and ordinary in the second:

$$\delta_{x1} = \frac{2\pi}{\lambda} (n - n_e) L = -\frac{4\pi}{3} BLE_1^2 = -\frac{4\pi}{3} BLE_0^2 - \frac{8\pi}{3} BLE_0 E_m \cos \Omega t$$

$$\delta_{x2} = \frac{2\pi}{\lambda} (n - n_o) L = \frac{2\pi}{3} BLE_2^2 = \frac{2\pi}{3} BLE_0^2 - \frac{4\pi}{3} BLE_0 E_m \cos \Omega t$$

and the total phase difference introduced for it by the fields applied at the two cells is:

$$\delta_x = \delta_{x1} + \delta_{x2} = -\frac{2\pi}{3} BLE_0^2 - \frac{12\pi}{3} BLE_0 E_m \cos \Omega t$$

With (10), (11) and (12) notations

$$\delta_x = \Phi_0 + \Phi_e - 3m \cos \Omega t = \Phi_a - 3m \cos \Omega t$$

where we have put:

$$\Phi_a = -\frac{2\pi}{3} BLE_0^2 \quad (22)$$

Similarly, for y component of the incident polarised light:

$$\delta_{y1} = \frac{2\pi}{3} BLE_1^2 = \frac{2\pi}{3} BLE_0^2 + \frac{4\pi}{3} BLE_0 E_m \cos \Omega t$$

$$\delta_{y2} = -\frac{4\pi}{3} BLE_2^2 = -\frac{4\pi}{3} BLE_0^2 + \frac{8\pi}{3} BLE_0 E_m \cos \Omega t$$

$$\delta_y = \Phi_a + 3m \cos \Omega t$$

If the polarised disturbance incident at the first cell is $ae^{-i\omega t}$, the disturbances polarised in the directions of the cells neutral lines, at the exit from the second cell, are*:

$$V_x(t) = \frac{a}{\sqrt{2}} e^{-i(\omega t + \Phi_a - 3m \cos \Omega t)}$$

$$V_y(t) = \frac{a}{\sqrt{2}} e^{-i(\omega t + \Phi_a + 3m \cos \Omega t)}$$

a) In *crossed arrangement*, the output disturbance from the modulator is written:

$$\begin{aligned} V_{\perp}(t) &= \frac{1}{\sqrt{2}} [V_x(t) - V_y(t)] = \frac{a}{2} e^{-i(\omega t + \Phi_a)} [e^{i \cdot 3m \cos \Omega t} - e^{-i \cdot 3m \cos \Omega t}] = \\ &= a \sin(3m \cos \Omega t) \cdot e^{-i\left(\omega t + \Phi_a + \frac{\pi}{2}\right)} \end{aligned}$$

With (1), the modulation function is.:

$$M_{\perp}(t) = \sin(3m \cos \Omega t) \cdot e^{-i\left(\Phi_a + \frac{\pi}{2}\right)} \quad (23)$$

b) In *parallel arrangement*:

$$V_{\parallel}(t) = \frac{1}{\sqrt{2}} [V_x(t) + V_y(t)] = a \cos(3m \cos \Omega t) e^{-i(\omega t + \Phi_a)}$$

and the transfer function of the corresponding modulator is:

$$M_{\parallel}(t) = \cos(3m \cos \Omega t) \cdot e^{-i\Phi_a} \quad (24)$$

From the Fourier development of the function $e^{iz \cos \theta}$:

$$\begin{aligned} e^{iz \cos \theta} &= \sum_{n=-\infty}^{\infty} C_n e^{-in\theta} = \sum_{n=-\infty}^{\infty} \left[\frac{1}{2\pi} \int_{-\pi}^{\pi} e^{iz \cos \theta} \cdot e^{in\theta} d\theta \right] \cdot e^{-in\theta} = \\ &= \sum_{n=-\infty}^{\infty} i^n J_n(z) e^{-in\theta} \end{aligned}$$

* The indices goes on marking the vibration directions of the light vector.

is obtained:

$$\begin{aligned}\cos(z \cos \theta) &= \sum_{n=-\infty}^{\infty} (-1)^n J_{2n}(z) \cdot e^{-i \cdot 2n\theta} = \\ &= J_0(z) + \sum_{n>0} (-1)^n J_{2n}(z) \cdot e^{-i2n\theta} + \sum_{n<0} (-1)^n J_{2n}(z) \cdot e^{i2n\theta} \\ \sin(z \cos \theta) &= \sum_{n=-\infty}^{\infty} (-1)^n J_{2n+1}(z) \cdot e^{-i(2n+1)\theta} = \\ &= \sum_{n\geq 0} (-1)^n J_{2n+1}(z) \cdot e^{-i(2n+1)\theta} + \sum_{n\geq 0} (-1)^n J_{2n+1}(z) \cdot e^{i(2n+1)\theta}\end{aligned}$$

so that the (23) and (24) modulation functions have the following spectral development:

$$\begin{aligned}M_{\parallel}(t) &= e^{-i\Phi_a} [J_0(3m) + \sum_{n<0} (-1)^n \cdot J_{2n}(3m) \cdot e^{-i2n\Omega t} + \\ &\quad \sum_{n>0} (-1)^n \cdot J_{2n}(3m) \cdot e^{i2n\Omega t}] \quad (25)\end{aligned}$$

$$\begin{aligned}M_{\perp}(t) &= e^{-i\left(\Phi_a + \frac{\pi}{2}\right)} \left[\sum_{n\geq 0} (-1)^n \cdot J_{2n+1}(3m) \cdot e^{-i(2n+1)\Omega t} + \right. \\ &\quad \left. + \sum_{n\geq 0} (-1)^n J_{2n+1}(3m) \cdot e^{i(2n+1)\Omega t} \right] \quad (26)\end{aligned}$$

The spectra of these modulation functions are represented in fig. 8 and 9.

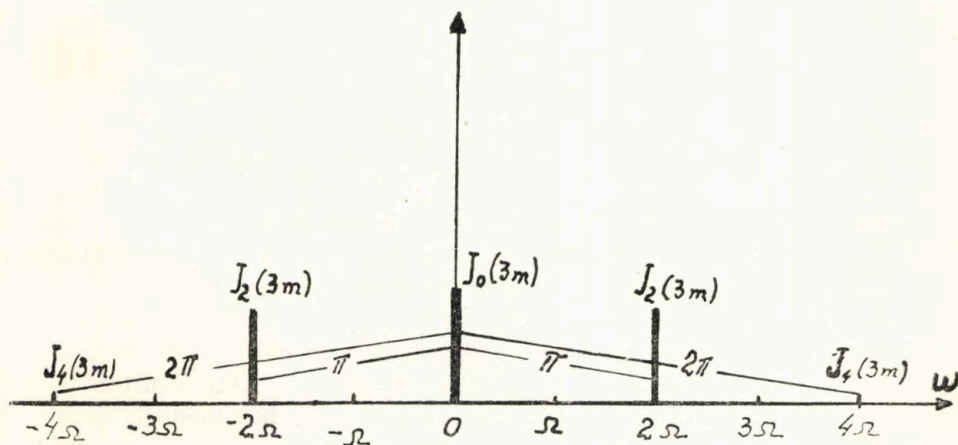


Fig. 8

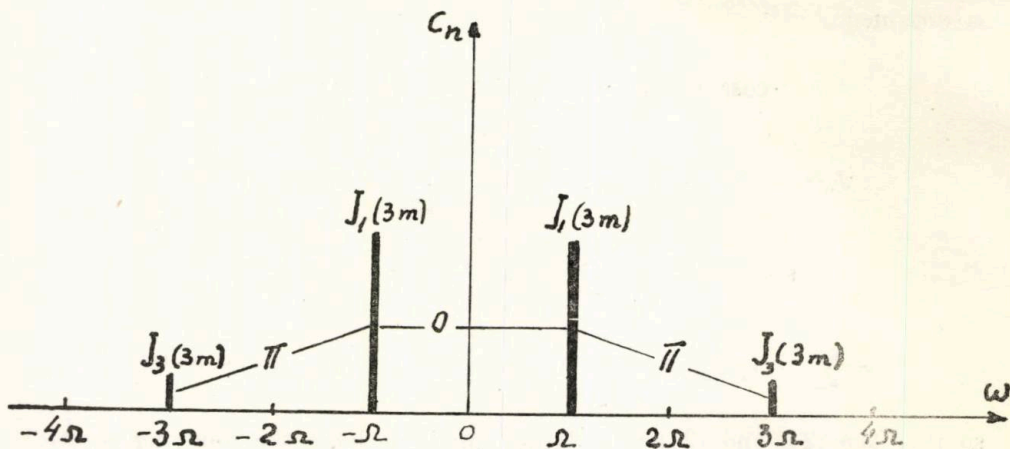


Fig. 9

In the case of the amplitude modulation in parallel arrangement, the amplitude of the initial monochromate diminishes in the ratio $J_0(3m)$, only even order lateral frequencies appear; the successive order monochromates are in opposition (at the origin):

$$V_{\parallel}(t) = J_0(3m) e^{-i\Phi_a} \cdot e^{-\omega t} + \sum_{n \geq 0} [J_{2n}(3m) e^{-i\Phi_a} \cdot e^{-in\pi} \cdot e^{-i(\omega - 2n\Omega)t} + J_{2n}(3m) \cdot e^{-i\Phi_a} \cdot e^{-n\pi} \cdot e^{-i(\omega + 2n\Omega)t}] \quad (27)$$

For crossed arrangement, the initial frequency disappears (the modulation is with the suppression of the carrier), it arises only odd order lateral frequencies, disposed simmetrically towards the initial one:

$$V_{\perp}(t) = \sum_{n \geq 0} \{ J_{2n+1}(3m) \cdot e^{-i\Phi_a} \cdot e^{-i(2n+1)\frac{\pi}{2}} \cdot e^{-i[\omega + (2n+1)\Omega]t} + J_{2n+1}(3m) \cdot e^{-i\Phi_a} \cdot e^{-i(2n+1)\frac{\pi}{2}} \cdot e^{-i[\omega - (2n+1)\Omega]t} \} \quad (28)$$

Similarly, in a complex treatment, it may be introduced a modulation function (1), for all kinds and methods of modulation, and, if the modulation is periodical, this function may be developed in the form (2).

From the above discussed examples, it may be seen that in some casis — for example (6) — the modulation function does not present dispersion, in others — (12), (19), (23), (24), by m dependence on Kerr constant — has dispersion, the action of modulation on different frequency monochromates is different.

3. THE SPECTRAL STRUCTURE OF THE LATERAL LINES APPEARED BY MODULATION.

In the above, we described for each exemplified modulation, the splitting action which it has on a ω monochromate — the formulae (8), (16), (21), (27), (28).

In the following, we shall go deeply into the study of the light spectral decomposition by modulation, investigating the modulation action on the real optical disturbance with any spectral profil.

Let be:

$$U(t) = \int_0^\infty u(\omega) \cdot e^{-i\omega t} d\omega \quad (29)$$

the complex analitic signal associated with the optical disturbance subjected to the modulation. According to (1), the output disturbance from the modulator is:

$$V(t) = \int_0^\infty M(t, \omega) \cdot u(\omega) \cdot e^{-i\omega t} d\omega \quad (30)$$

and using the modulation function spectral development (2),

$$V(t) = \sum_n \int_0^\infty c_n(\omega) \cdot u(\omega) \cdot e^{-i(\omega+n\Omega)t} d\omega$$

Thus, the output disturbance consist of a series of spectral components of the form:

$$V_n(t) = \int_0^\infty c(\omega) \cdot u(\omega) \cdot e^{-(\omega+n\Omega)t} d\omega$$

On the other hand, the analitic signal of such a component may be developed:

$$V_n(t) = \int_0^\infty v_n(\omega) \cdot e^{-i\omega t} d\omega = \int_0^\infty v_n(\omega + n\Omega) \cdot e^{-i(\omega+n\Omega)t} d\omega$$

and, by identification between the last two:

$$v_n(\omega + n\Omega) = c_n(\omega) \cdot u(\omega) \quad (31)$$

If the modulation function has not dispersion, or if its dispersion is negligible on the spectral range of the incident light,

$$v_n(\omega + n\Omega) = c_n \cdot u(\omega) \quad (32)$$

the spectrum of n — order component is obtained, up to a complex factor — the same for all the constituent monochromates — by a translation $n\Omega/2\pi$ in the frequency scale, of the initial line. The complex amplitudes of a sideband monochromates differ from the complex amplitudes of the corresponding monochromates of the incident line (the monochromates identically distanced from the line centre) by a generally complex (diminution, $|C_n|$; phase difference,

arg C_n) factor, the same for all the corresponding monochromate pairs. The observable (intensity) spectrum of a sideband, has an identical profil with that of the incident light, their difference consisting only of a diminution factor, generally:

$$|v_n(\omega + n\Omega)|^2 = |C|^2 \cdot |u(\omega)|^2 \quad (33)$$

Particularly, the sideband width is equal to that of the initial line. Indeed, if $\Delta\omega$ and, respectively, $\Delta\omega_n$ denote the half-widths of the initial line and of the n — order sideband, it may be written:

$$|u(\omega_0 \pm \Delta\omega)|^2 = \frac{1}{2} |u(\omega_0)|^2 \quad (34)$$

$$|v_n(\omega_0 + n\Omega \pm \Delta\omega_n)|^2 = \frac{1}{2} |v_n(\omega_0 + n\Omega)|^2$$

With (33), and after simplification, the last becomes:

$$|u(\omega_0 \pm \Delta\omega_n)|^2 = \frac{1}{2} |u(\omega_0)|^2 \quad (35)$$

and, by identification between (34) and (35):

$$\Delta\omega_n = \Delta\omega \quad (36)$$

These last results are obtained on condition of the inexistence or negligibility of the modulation function dispersion; otherwise, the corresponding results are obtained from (31), taking into account the dispersion law of the modulation function. But what is important is the fact that this condition is satisfied in all the cases of practical interest. We shall show this fact for the above established modulation function examples.

3.1. Mecanical Amplitude Modulation.

The modulation function (6), or a similar one, has not dispersion. The Fourier coefficients, (7), of the modulation function do not depend on the modulated frequency, the action of the modulation on all the monochromates of the intial line is identical, and the (32)—(36) results are rigorously valid.

3.2. Electro-Optical Phase Modulation.

a) If the incident light is extraordinary in the cell, the modulation function is given by the expression (12) and, by Φ_e and m — (10) and (11) — together with the Kerr constant, has dispersion. From the table II, ([3] p. 145) it results that the maximum dispersion of the nitrobenzen Kerr constant, in the visible spectrum, is of about $2 \times 10^{-13} \frac{cm}{V^2 \cdot \text{\AA}}$, which corresponds to a relative dispersion of about $4 \cdot 10^{-4}$.

TABLE Nr. 2.

$\lambda(\mu)$	$B \times 10^{10} \left(\frac{cm}{V^2} \right)$
0.500	5.5
0.525	5.2
0.550	5.0
0.575	4.5
0.600	4.3
0.625	4.1
0.650	4.0
0.675	3.7
0.700	3.6

The usual values of the working parameters in an electro-optical modulation with nitrobenzen are of the order of magnitude of the values at which Connes worked [2]: the d.c. voltage $U_0 = 3kV$, the alternating voltage amplitude $U_m = 500V$, the electrodes spacing $d = 0.2 \text{ cm}$, their length $l = 5 \text{ cm}$.

Working to the breakdown voltage limit (for overpurified nitrobenzen $E_b = 150 \frac{kV}{cm}$, [3] p. 145) and to the limit imposed to the ratio d^2/l by diffraction ([3] p. 86), it may be obtained, with some precautions, [6], working parameters of the order of $U_0 = 30kV$; $U_m = 2kV$; $d = 0.2 \text{ cm}$; $l = 10 \text{ cm}$.

For these two groups of parameters, we present in table III, the values of m and its absolute and relative dispersions. The amplitude, $2m$, of the phase

TABLE Nr. 3

	usual values	limit values
$m = \frac{4\pi}{3} BLE_0 E_m$	$0.125\pi \text{ rad.}$	$10\pi \text{ rad.}$
$\frac{\partial m}{\partial \lambda} = \frac{4\pi}{3} \frac{\partial B}{\partial \lambda} LE_0 E_m$	$5\pi \cdot 10^{-5} \frac{\text{rad}}{\text{\AA}}$	$4\pi \cdot 10^{-3} \frac{\text{rad}}{\text{\AA}}$
$\frac{\partial m / \partial \lambda}{m} = \frac{\partial B / \partial \lambda}{B}$	$4 \cdot 10^{-4}$	$4 \cdot 10^{-4}$

oscillation is, in the first case appreciable (0.25π), in the second—great (20π). In both cases its dispersion is small ($\approx 1 \frac{\text{minute}}{\text{\AA}}$; $\approx 1.5 \frac{\text{degrees}}{\text{\AA}}$). The relative dispersion of the phase oscillation amplitude is small ($4 \cdot 10^{-4}$), the phase oscillates in the same rhythm and, for quasi-monochromatic light (for example $\Delta\lambda = 0.1\text{\AA}$), practically on the same range, for all the constituent monochromates

of the line. One may not say the same thing if the spectral width of the light subjected to the modulation is great. But the width of $\Delta\lambda = 0.1\text{\AA}$, is at the upper limit of the situations of practical interest: In order we can make a structure comparison of the sidebands with the initial line, the latter must be effectively splitted by modulation. As the modulation frequencies do not exceed, up to present, the order of 10 GHz. ([7],[4],[3]), for the line may be splitted, also its width must not exceed this order of magnitude, which, in visible, means 0.1\AA.

We shall now examine in what measure the above calculated dispersions for the parametre m , may lead to a modification of the spectral profil of the sideband, in comparison whit that of the initial line. From (33) formula it results that a such modification takes places if the modulus of the corresponding Fourier coefficient of the modulation function has an appreciable dispersion on the spectral range of the light subjected to the modulation.

An obvious formulation of a sufficient condition for n -order lateral component profile to be practically the same to that of the initial line — we understand all the time, the existence of a diminution factor — is:

$$\left| \frac{d|c_n|^2}{d\lambda} \right| \cdot \Delta\lambda \ll |\bar{C}_n|^2 \quad (37)$$

hence:

$$R = \frac{2 \left| \frac{d|c_n|}{d\lambda} \right| \cdot \Delta\lambda}{|\bar{C}_n|} \quad (38)$$

where $\Delta\lambda$ is the width of the light subjected to the modulation and C_n the modulation function n — order coefficient, calculated for a mean frequency of the line.

From (13), in this case:

$$|C_n| = |J_n(2m)|$$

Taking into account the fact that:

$$\left| \frac{d|J_n(z)|}{dz} \right| = \left| \frac{dJ_n(z)}{dz} \right|,$$

$$\frac{dJ_n(z)}{dz} = \frac{1}{2} J_{n-1}(z) - \frac{1}{2} J_{n+1}(z)$$

and

$$|J_{n-1}(z) - J_{n+1}(z)| \leq |J_{n-1}(z)| + |J_{n+1}(z)| \leq 2$$

from (38) is obtained:

$$R_{Eo.} \leq \frac{4 \left| \frac{dm}{d\lambda} \right| \Delta\lambda}{|J_n(2m)|} \quad (39)$$

With $\Delta\lambda = 0.1\text{\AA}$, in the conditions of some usual working parameters for which, for example $|dm/d\lambda| \sim 2 \times 10^{-4} \frac{\text{rad}}{\text{\AA}}$ (see table II) — if $|J_n(2m)|^2 \gg \gg 10^{-4}$, then $R < 10^{-2}$. In other words, in these conditions, the spectral profil modifications between the initial line and the side component, may exceed 1%, only if this component is of 10^{-4} times less intense than the initial line.

In more difficult working condition — for which, for instance $|dm/d\lambda| \sim \sim 1.2 \times 10^{-2} \frac{\text{rad}}{\text{\AA}}$ (table II) — if $|J_n(2m)|^2 \gg 10^{-2}$, then $R < 5 \times 10^{-2}$, hence the spectral profil modifications are under 5%, if the side component intensity does not exceed 1% from that of the initial line.

b) If the incident light is ordinary in the cell, the modulation function is given by the expression (19), the dispersions are two times more reduced,

$$|C_n| = |J_n(m)|$$

and

$$R_o \leq \frac{2 \left| \frac{dm}{d\lambda} \right| \Delta\lambda}{|J_n(m)|} \quad (40)$$

in corresponding conditions, the spectral profil modifications are more reduced than those discussed above.

3.3. Electro-Optical Amplitude Modulation.

From (25) and (26), it results that, for the amplitude modulation, the modules of the Fourier coefficients of the modulation functions are:

$$|C_n| = |J_n(3m)|$$

where n takes either only even, or only odd values, as the arrangement is parallel or crossed.

Using this expresison in (38), it is obtained:

$$R \leq \frac{6 \left| \frac{dm}{d\lambda} \right| \Delta\lambda}{|J_n(3m)|}$$

In the conditions which we have considered as representative for the usual ones, if $|J_n(3m)|^2 \gg 10^{-4}$, then $R \leq 1.2 \times 10^{-2}$, the spectral profil modifications between the initial line and a side component, may exceed 1.2% only if the intesity of this component is under 10^{-4} from that of the initial line.

In nowadays limit working conditions, if $|J_n(3m)|^2 \geq 10^{-2}$, then $R \leq 7.2 \times 10^{-2}$, the spectral profil modifications do not exceed 7.2% if the side component intensity is more than 1% from that of the initial line.

We conclude that, for quasi - monochromatic light, in conditions of working parameters realised up to present, the modulation functions dispersions, when they exist, are negligible from the point of view of the spectrale profile modifications of the side components in comparison to the initial line. Thus, the final results, (32) — (36), of the theory built by us at the begining of the second chapter, cover all the situations of practical interest arisen up to now.

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SUR LA FORME DES RAIES SPECTRALES OBTENUES PAR UNE DÉCHARGE EN VAPEUR DE Hg À HAUTE PRESSION

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RÉSUMÉ

Dans cette étude sont examinées les caractéristiques des profils des raies 435,83 nm et 546,07 nm du Hg produites dans une lampe de décharge à haute pression. On donne les valeurs des demi-largeurs et la dépendance des celles-ci des conditions d'excitation.

On montre que dans certaines conditions de sous-alimentation de la décharge, les radiations obtenues ont une grande finesse, et l'on peut les utiliser dans les buts metrologiques ou dans les mesures interférométriques comme les radiations étalon de référence.

INTRODUCTION

Etudiant une série de lampes de décharge aux vapeurs de Hg à haute pression et analysant les profils des radiations spectrales émises on a obtenu une série de dates concernant le comportement des radiations en fonction des conditions où on entretient la décharge de la lampe.

Le régime de fonctionnement de la lampe à vapeur de Hg à haute pression peut être caractérisé en principal par une température élevée et des collisions intenses entre les particules. C'est pourquoi les radiations émises par une telle lampe seront fort déformées à la suite des effets Doppler, Lorentz et Stark [1], [2], [3].

On peut prévoir que les radiations émises auront des profils larges — probablement avec autoabsorption prononcée — asymétriques et avec la valeur de la longueur d'onde déplacée [4].

Le schéma constructif de la lampe à vapeur de Hg à haute pression étudiée est présenté dans la figure 1. La lampe est constituée d'un ballon en quartz (1), des électrodes principaux (2) et (3) et un électrode auxiliaire (4). Le ballon contient des gouttes de Hg qui s'évaporent pendant le fonctionnement

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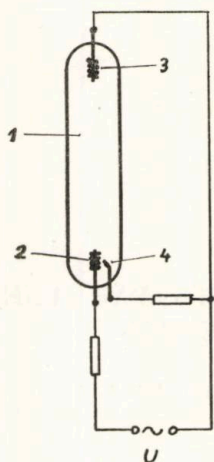


Fig. 1

de la lampe et produisent une pression du vapeur à peu près 3...4 atm. Pour amorcer la décharge initiale, dans le ballon on introduit une quantité d'argon à la pression d'à peu près 40 mm Hg.

RESULTATS EXPERIMENTAUX

Pour cette étude ont été choisies les radiations $6^3P_1^0 - 7^3S_1$ avec la longueur d'onde 435,83 nm et $6^3P_2^0 - 7^3S_1$ avec la longueur d'onde 546,07 nm.

La lampe a été prévue avec un thermocouple pour la mesure de la température du paroi pendant l'enregistrement des profils spectraux. En outre, le courant de décharge, la chute de la tension et la puissance absorbée par la lampe ont été mesurés tout le temps.

Etant donné qu'on a constaté que le courant de décharge exerce une influence remarquable sur le profile spectral, le circuit d'alimentations de la lampe a été prévu avec un rhéostat. A l'aide de cette résistance variable, le courant de décharge a été diminué de 1,1 A (le courant maximum dans les conditions normales de fonctionnement) jusqu'à 0,48 A. Pour des valeurs plus réduites du courant, la colonne de décharge se déforme et perd sa stabilité.

Dans ces conditions ont été effectuées plusieurs enregistrements représentés dans les figures 2...15. Les enregistrements ont été effectués avec un interféromètre Fabry-Perot avec des plaques en verre couvertes d'une couche d'argent, ayant la distance d entre les plaques variable de 0 à 100 mm.

La figure 2 présente le profile de la raie 435,8 nm au courant de 1,09 A. La raie a une largeur remarquable. C'est pourquoi il faut que l'enregistrement soit fait avec une distance entre les plaques plus petite que celle utilisée pour les petits courants. On observe une autoabsorption remarquable et on calcule une demi-largeur de $14,22 \text{ cm}^{-1}$.

Les figures 3...8 présentent les profiles de la même raie enregistrés dans les conditions les plus adéquates d'enregistrement, aux courants de décharge différents. C'est facile à observer le changement, plus précisément le resserrement de la raie spectrale au moment de la diminution de l'intensité du courant. On observe que la raie devient de plus en plus symétrique, l'autoabsorption se diminue et au courant d'environ 0,48 A (fig. 7), la largeur de la raie est tellement petite qu'on peut résoudre certaines structures hyperfines. Pour comparaison on a enregistré dans les mêmes conditions d'enregistrement le profile de la ligne 435,8 nm d'une lampe à Hg étalon à basse pres-

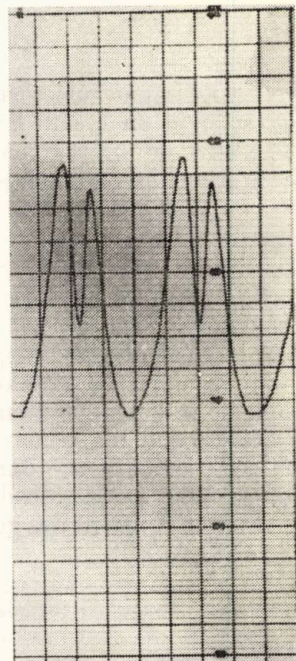


Fig. 2. $i = 1,09 \text{ A}$
 $d = 0,3 \text{ mm}$

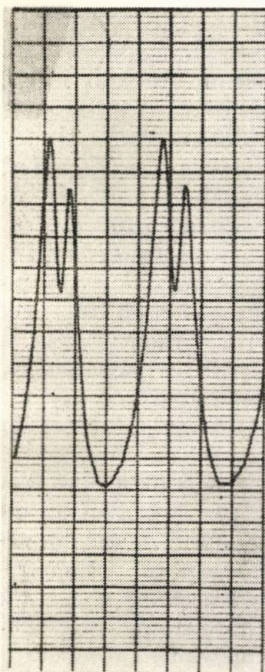


Fig. 3 $i = 0,93$ A
 $d = 0,3$ mm

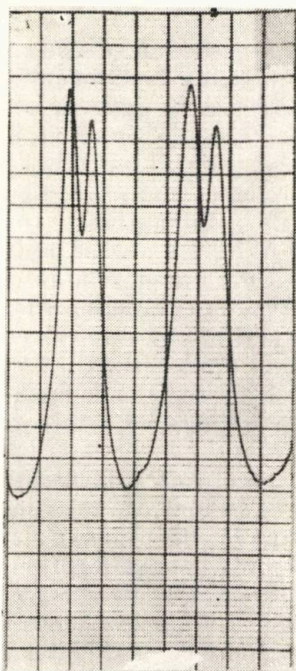


Fig. 4 $i = 0,88$ A
 $d = 0,5$ mm

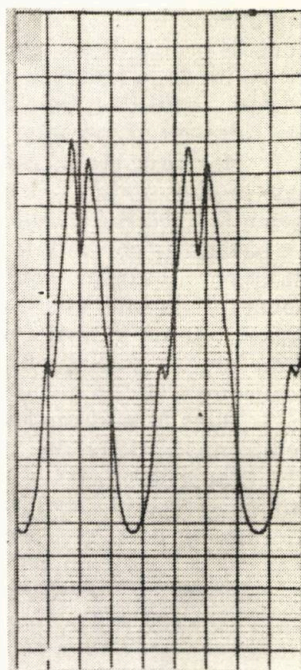


Fig. 5 $i = 0,67$ A
 $d = 1,5$ mm

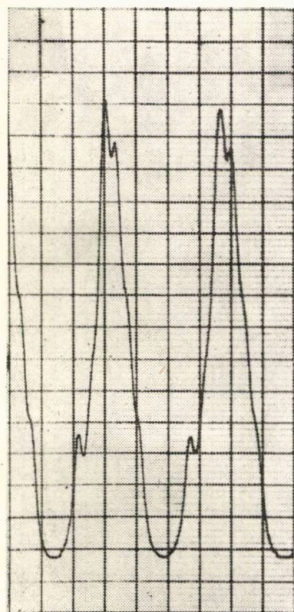


Fig. 6. $i = 0,57$ A
 $d = 1,5$ mm

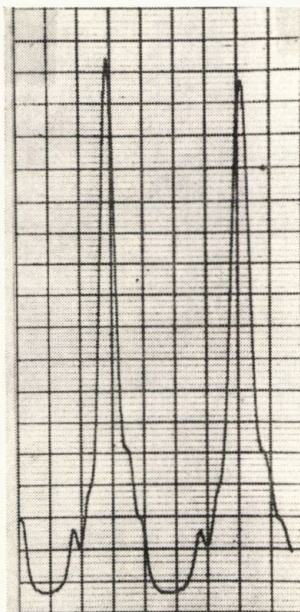


Fig. 7. $i = 0,48$ A
 $d = 1,5$ mm

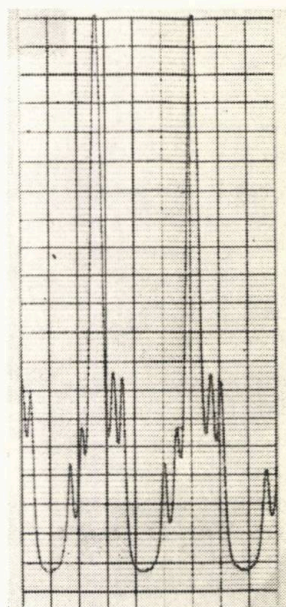


Fig. 8 $i = 0,3$ A
 $d = 1,5$ mm

sion. Le profile de cette radiation est donné dans la figure 8. On constate que le profile de la lampe à haute pression fonctionnant au courant de 0,48 A est presque identique avec le profile de la ligne de lampe étalon, la demi-largeur des raies étant presque égale ($\delta = 0,56 \text{ cm}^{-1}$ et $\delta_e = 0,53 \text{ cm}^{-1}$).

Des enregistrements similaires ont été effectués pour la radiation 546,1 nm. Les profiles obtenus sont présentés dans les figures 9...15. Analysant la forme des profiles en fonction de la diminution du courant et comparant le profile obtenu au courant de 0,48 A (fig. 14) avec le profile de la raie étalon (fig. 15) on arrive à la même conclusion. La diminution du courant conduit au resserrement de la raie, à la disparition de l'autoabsorption et on obtient en final une raie étroite où la structure hyperfine put être relevée. Cette dernière raie a la demi-largeur de $0,22 \text{ cm}^{-1}$ mais sa forme et ses caractéristique ressemblent beaucoup à la raie de la même longueur d'onde de la lampe étalon.

Dans le tableau 1 sont présentées les demi-largeurs totales mesurées en conditions différentes.

En général, les profiles spectraux présentent pour les deux radiations une décroissance très forte de la largeur des raies imposée par la réduction du courant de décharge. Analysant les diagrammes dans la figure 16 qui représentent la variation de la demi-largeur en fonction du courant de décharge on constate qu'il existe une portion dans l'augmentation du courant d'environ 0,4 A (de 0,67 A à 1,1 A) où la demi-largeur augmente d'abord en quelque sorte linéaire et puis brusquement. Dans ce même intervalle apparait l'autoabsorption qui croît continuellement avec l'augmentation du courant.

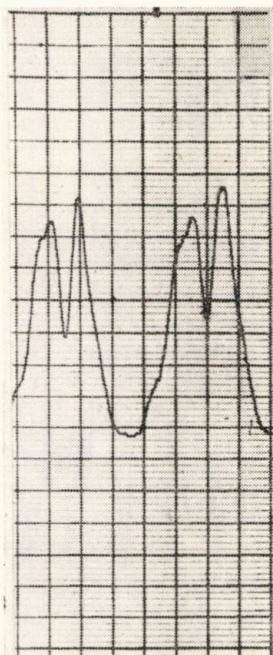


Fig. 9. $i = 1,08 \text{ A}$
 $d = 0,5 \text{ mm}$

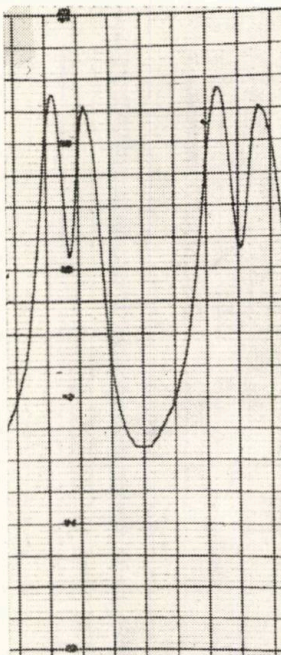


Fig. 10. $i = 0,90 \text{ A}$
 $d = 1 \text{ mm}$

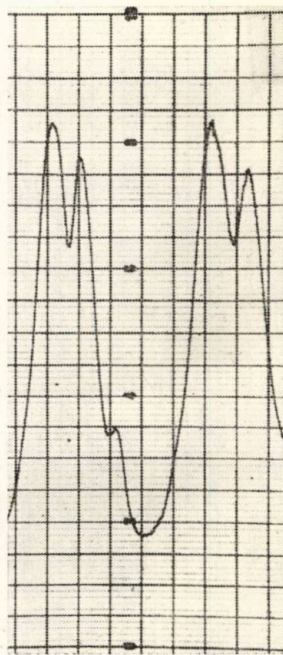


Fig. 11. $i = 0,70 \text{ A}$
 $d = 2 \text{ mm}$

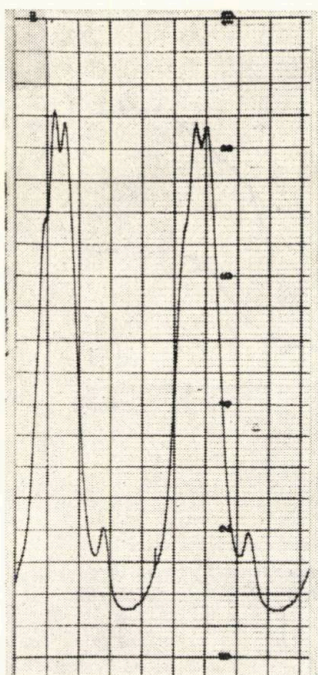


Fig. 12. $i = 0,57$ A
 $d = 2$ mm

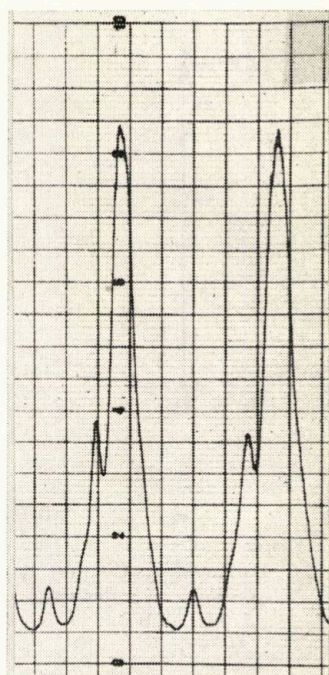


Fig. 13. $i = 0,51$ A
 $d = 3$ mm

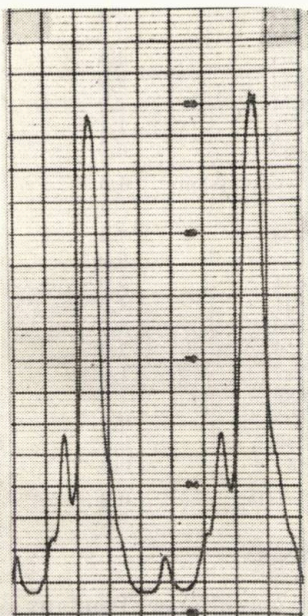


Fig. 14. $i = 0,48$ A
 $d = 3$ mm

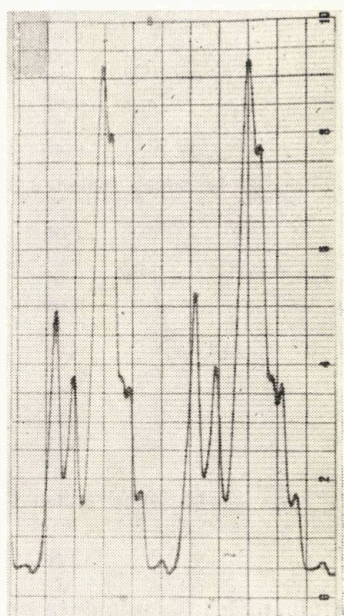


Fig. 15. $i = 0,3$ A
 $d = 3\text{mm}$

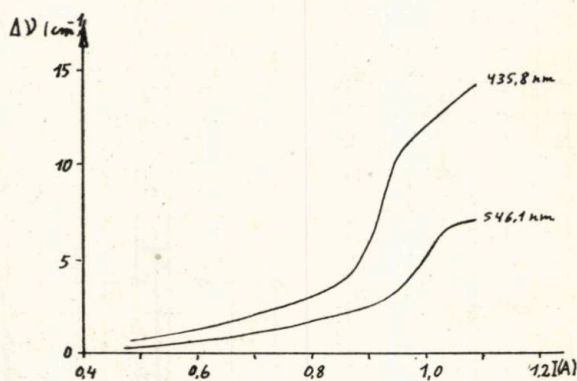


Fig. 16

TABLEAU Nr. 1.

Longueur d'onde λ (nm)	Courant de décharge I (A)	Température du ballon T (K)	Demi-largeur de la raie δ (cm ⁻¹)
435,8	1,09	886	14,2
	1,04	877	12,8
	0,95	851	10,1
	0,93	821	8,3
	0,91	793	7,0
	0,88	761	4,5
	0,79	724	2,9
	0,67	670	1,9
	0,57	621	1,1
	0,48	503	0,5
La lampe étalon à Hg à basse pression			0,5
546,1	1,08	879	7,0
	1,04	877	6,9
	1,01	851	5,9
	0,99	821	4,4
	0,96	793	3,7
	0,90	755	2,7
	0,79	727	1,9
	0,70	689	1,1
	0,57	625	0,7
	0,51	532	0,3
	0,48	483	0,2
La lampe étalon à basse pression			0,2

DISCUSSIONS.

Evidemment les phénomènes sont facile à expliquer. Pendant la décharge la lampe contient la vapeur de mercure et mercure liquide. L'augmentation du courant conduit à l'augmentation de la température dans la colonne de décharge

et en général dans le ballon de la lampe. Cette chose aura deux conséquences. Premièrement le mercure supplémentaire s'évapore et par conséquent la pression des vapeurs croît. Secondement, une différence de température est créée de plus en plus grande entre la colonne de décharge et le paroi du ballon de la lampe.

La première conséquence conduit à l'agitation thermique plus grande dans la colonne de décharge où la densité des atomes excités et nonexcités croît avec l'augmentation du courant. Cette augmentation de la densité des particules dans la colonne de décharge provoque l'augmentation de l'effet de la pression et en même temps, mais dans une moindre mesure, de l'effet Doppler. Ces deux effets conduisent évidemment à la croissance substantielle de la largeur de la raie.

La seconde conséquence qui produit une augmentation de la différence de température entre la colonne de décharge et la température du paroi du ballon, conduit à l'apparition et à l'augmentation de l'autoabsorption. Le degré de l'autoabsorption A_a :

$$A_a \equiv 1 - \frac{I_a}{I_0}$$

(I_0 — l'intensité initiale, I_a — l'intensité finale), en fonction du courant de décharge est représenté dans la figure 17.

Les courbes dans les figures 16 et 18 qui présentent la variation de la demi-largeur de la raie en fonction de la température et la variation de la température en fonction du courant, sont très intéressantes. On voit qu'entre 0,9 A et 1,1 A la température croît brusquement avec le courant (fig. 18). Cela produit une évaporation forte et par conséquent l'apparition d'une quantité massive d'atomes de Hg dans la colonne de décharge. L'augmentation brusque de la pression se manifeste tout-de-suite par une augmentation substantielle de la demilargeur des raies (fig. 16).

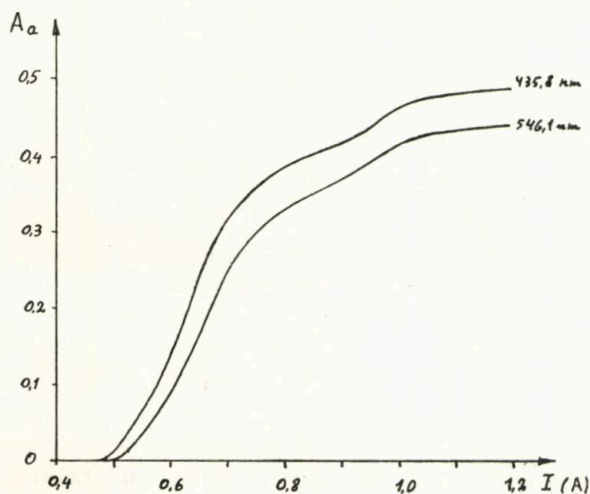


Fig. 17

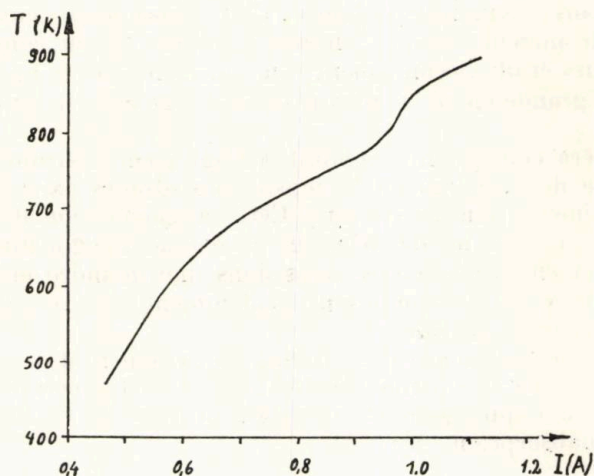


Fig. 18

Nous mentionnons que l'inconcordanace des valeurs aux quelles la température et la demi-largeur augmentent brusquement est du au fait que la température dans la figure 18 ne représente pas la température de la colonne de décharge mais la température du paroi.

Analysant les raison par suite des quelles on obtient ce fort élargissement avec l'augmentation du courant on peut souligner que l'augmentation de la température impose une augmentation de l'élargissement du profile spectral en conformité avec la relation Doppler [5/, /6/, /7/, /8/.

Cependant, les calculs théoriques montrent que cette augmentation de la température, possible pour un courant minime et pour un courant maximum de décharge, ne peut pas produire qu'un très petite part d'augmentation totale obtenne.

On résulte donc que le reste d'augmentation de demi-largeur est dû à l'effet de pression produit par l'effet de collision de type Lorentz [9/, /10/ et l'effet d'élargissement de type Stark [5/, /11/.

Dans le but d'avoir une vue plus complète sur le comportement des radiations obtenues dans la lampe de Hg à haute pression, ont été effectuées des déterminations sur les déplacements des raies spectrales en fonction du courant de décharge. Les mesure ont été effectués par rapport à la valeur de la longueur d'onde de la lampe étalon de Hg à basse pression.

Les valeurs obtenues (le tableau 2) montrent qu'au courant de 0,48 A, la raie examinée (435,8 nm) ne presente pas des déplacements dans les limites des erreurs de mesure et l'augmentation du courant provoque des déplacements relativement petits.

La valeur de 0,48 A du courant est une valeur critique par le fait qu'elle est la limite au-dessous de laquelle la décharge devient instable. Elle est aussi la valeur à la quelle la longueur d'onde coincide à la valeur de la même radia-

tion de la lampe étalon, la finesse des raies augmente, l'autoabsorption disparaît et ainsi la radiation non déformée peut être utilisée comme radiation étalon pour référence.

TABLEAU Nr. 2

Les déplacements de la raie 435,8 nm $\Delta\lambda(\text{nm})$	Le courant de décharge I (A)
$-0,49 \cdot 10^{-4}$	0,48
$-3,03 \cdot 10^{-4}$	0,63
$-3,05 \cdot 10^{-4}$	0,84
$-3,07 \cdot 10^{-4}$	0,94
$-4,56 \cdot 10^{-4}$	1,0

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ZEEMAN EFFECT FOR FREQUENCIES WITHIN 10—20 MHZ

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ABSTRACT

This paper presents the experimental results obtained in the study of the absorption of the high frequency electromagnetic field by the plasma in the negative light of a d.c. discharge in the presence of a uniform magnetic field and at pressures below 10^{-3} mmHg.

It is shown that these absorptions, for pressures of the order of 10^{-3} — 10^{-4} mmHg are due to the Zeeman effect for high quantum numbers.

1. INTRODUCTION

Some previous studies [1], [2] have put into evidence the existence of three absorption groups which appear in the presence of a uniform magnetic field at pressures below 10^{-3} mmHg and discharge currents of 0.3 mA. The studies have been carried out in the frequency band 5—20 MH. Three absorption groups have been put into evidence in the negative light of a d.c. discharge, the discharge gases being NO, O₂, Ne and H₂.

The absorption groups have been obtained either by keeping constant the working frequency and varying the magnetic field, or by keeping constant the magnetic field and varying the working frequency.

The absorptions which constitute the three groups have been identified as being $+\sigma$ components of the Zeeman splitting of the quasi-free electrons for high quantum numbers.

The absorptions recorded in magnetic field take place for values of this field higher than those corresponding to the cyclotron frequency. The value of the magnetic field at which absorptions take place is a logarithmic function of the discharge current intensity.

2. THEORY

For the sake of simplifying the reasoning it has been assumed that the electron paths are circular and situated in planes perpendicular to magnetic

field. On the basis of the reasonings employed we have obtained the following relations [2], [3]:

$$\pm \frac{1}{2} \left(\frac{l^2}{r_1'} - \frac{l^2}{r_2'} \right) \pm H\mu_B(n_1' - n_2') = h_c R - \left[\frac{1}{(n_1')^2} - \frac{1}{(n_2')^2} \right] = h\nu \quad (1)$$

$$\pm \frac{1}{2} \left(\frac{l^2}{r_1''} - \frac{l^2}{r_2''} \right) \pm H\mu_B(n_1'' - n_2'') = h_c R - \left[\frac{1}{(n_1'')^2} - \frac{1}{(n_2'')^2} \right] = h\nu \quad (2)$$

In relations (1) and (2) e stands for the electron charge and r for the radius of its orbit; μ_B is Bohr's magneton and h and R are Plank's and Rydberg's constants.

The term $\Delta E_e = \pm \frac{1}{2} \left(\frac{l^2}{r_1} - \frac{l^2}{r_2} \right)$ represents the variation of the Coulomb potential energy and the term $\Delta E_H = \pm H\mu_B(n_1 - n_2)$ the variation of the magnetic energy.

Accordingly, we may write

$$\pm \Delta E_e \pm \Delta E_H = h\nu$$

that is

$$\pm \nu_e \pm \nu_H = \nu \quad (3)$$

It has been admitted that under the experimental conditions in which we have worked only the energy absorption could be obtained; in such a case relation (3) may be written as

$$\pm \nu + \nu = \nu \quad (4)$$

Since the energy absorption appear only in the presence of the magnetic field it has been assumed that the electron path is quantified only in the presence of the magnetic field.

The experimental results have shown however that ν_e , ν and ν_H are related by

$$\nu = \alpha\nu + \beta\nu \quad (5)$$

where $\beta > 0$ and α can be positive, negative or zero.

3. EXPERIMENTAL APPARATUS

The absorptions of high frequency electromagnetic waves have been put into evidence with the aid of a capacitive bridge independent of frequency, described in other papers [4], [5].

The Faraday region and the negative light of a d.c. discharge have been studied. The ionized gas was in a tube of 90 cm length and 20 cm diameter. Two discs, one of aluminium and the other of iron, attached to the tube end

with araldit constituted the anode and the cathode; they could be grounded as concerns the high frequency, being shortcircuited with the aid of a 4 nF condenser.

The d.c. voltage supplied to the tube could be varied at will between 0 and 5 kV.

The tube was placed between the plates of a condenser connected to one of the measuring bridge arms.

The uniform magnetic field, parallel to the tube axis was obtained with the aid of a Helmholtz coil with a mean radius of 52 cm, able to give in the plasma region a field of 7.4 Oe when a 1 A current was passed through the coil.

The recordings were photographically obtained by applying on the oscillograph horizontal deflection plates a tension proportional to the current passing through the coil, hence to the magnetic field H ; to the frequency ν of the high frequency field applied to the measuring bridge, hence also applied to the coupling condenser; proportional to the ionization current intensity; to the intensity of the high frequency field applied to the measuring bridge, or to the distance between anode and cathode when the coupling condenser was displaced along the discharge tube.

4. EXPERIMENTAL RESULTS, DISCUSSION

The recordings were obtained by using oxygen as discharge gas.

The experimental conditions in which the recordings shown in Fig. 1 were obtained are given in Table 1.

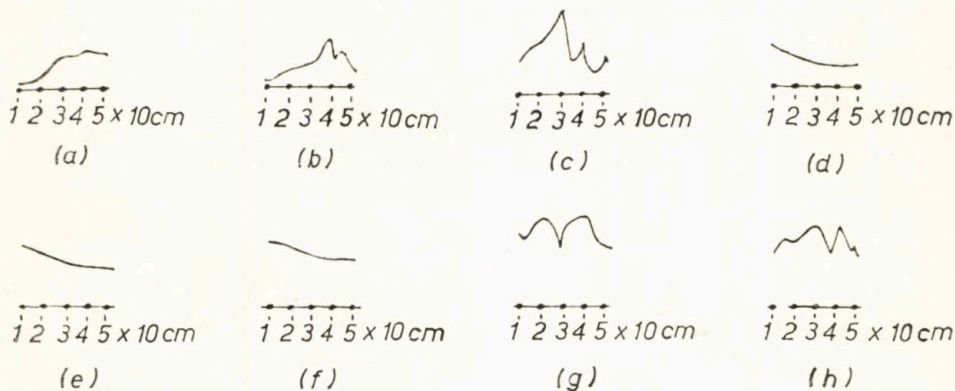


Fig. 1 — Recordings obtained by displacing the coupling condenser along the discharge tube

TABLE Nr. 1

Fig. 1	a	b	c	d	e	f	g	h
ν (MHz)	20	20	20	20	12	15	18	20
I (mA)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
$p \times 10^4$ (mmHg)	2.5	2.1	2.3	0.2	2.1	2.3	2.0	2.0
H(Oe)	0	5.5	9.2	15.8	10	10	10	10

Working at a fixed frequency ($\nu = 20$ MHz), with a constant magnetic field, constant ionization intensity and constant pressure and displacing the coupling along the discharge tube, absorption peaks as shown in Fig. 1 b,c were recorded. The absorption peaks have the highest intensity for $H = 9.2$ Oe (Fig. 1c); they do not appear for $H = 0$ and $H = 15.8$ Oe (Figs. 1a,d).

By keeping constant the magnetic field H as well as the other experimental conditions and displacing the coupling condenser along the discharge tube, for various values of the working frequency ν , we obtained the recordings shown in Figs. 1 e,f,g,h. The distances indicated in Fig. 1 are measured with respect to the anode.

It may be observed that these peaks do not appear at all working frequencies and the shape of the curves changes from one frequency to another.

Fig. 2 shows a recording obtained function of the intensity of the uniform magnetic field H for an output tension of the high frequency generator equal to 5 V. One may observe the appearance of the absorption groups indicated at the beginning of the paper ($p = 2 \times 10^{-4}$ mmHg; $I = 0.3$ mA; $\nu = 17$ MHz).

In the same experimental conditions, by keeping constant the uniform magnetic field ($H = 9.2$ Oe) and varying the output tension of the high frequency generator (hence also the intensity of the high frequency electromagnetic field between the coupling condenser plates) one obtains a curve as that marked by 1 in Fig. 2b.

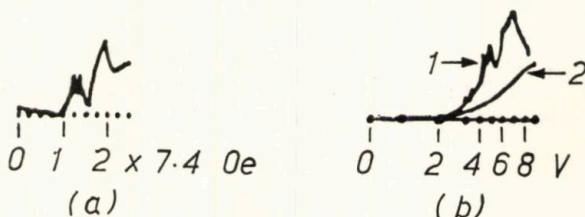


Fig. 2 — (a) Recording obtained function of the intensity of the uniform magnetic field H ; (b) Absorption peaks obtained function of the intensity of the highest frequency electro-magnetic field.

Consequently, for these pressures, absorption peaks function of the intensity of the high frequency electromagnetic field are recorded when all other experimental conditions remain unchanged. Also, have been put into evidence absorption peaks function of the discharge current intensity in tube, working with hydrogen [6].

For pressures higher than this value, although the three groups are obtained function of the intensity of the uniform magnetic field H , a smooth curve as that marked by 2 in Fig. 2b is obtained function of the intensity of the high frequency electromagnetic field.

The appearance of absorption peaks obtained by displacing the coupling condenser along the discharge tube (Fig. 1) could be due to the formation in plasma of some regions of maximum probability for the performing of one of the transitions between the Zeeman splitting levels.

The appearance of the absorption peaks obtained function of the intensity of high frequency electromagnetic field could be explained by variation of the term of the Coulomb potential energy (ΔE_e) from the relation $\pm \Delta E_e \pm \Delta E_H = h\nu$.

The authors would like to express once more their best thanks and their indebtedness to Professor Theodor V. Ionescu, for the guidance and support given in the preparation of this work.

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DIE VERBESSERUNG DER ELEKTRISCHEN CHARAKTERISTIKEN DER BLEIAKKUMULATOREN DURCH BEHANDLUNG DES ELECTROLYTEN MIT ULTRASCHALL

V.P. MIHU und I. GAVRILĂ

Dans cet ouvrage on étudie la modification des caractéristiques électriques des accumulateurs à plomb, avec l'électrolyte ultrasoné.

On constate des augmentations des courants de décharge et de la capacité des cellules à l'électrolyte ultrasoné, ainsi qu'une augmentation de la durée de fonctionnement de l'accumulateur.

1. EINFÜHRUNG

Die elektrischen Akkumulatoren sind die wichtigsten chemischen Erzeuger von elektrischer Energie. Deshalb bildete die Verbesserung der Betriebsparameter dieser eine ständige Sorge vieler Physiker.

Aus den in der Fachliteratur veröffentlichten Arbeiten geht hervor, dass die Untersuchungen besonders auf die Erzielung von Entladungsströmen grosser Stärke und grösserer Lieferungskapazitäten der betreffenden Zellen ausgerichtet waren, durch Hinzufügung zur benötigten Schwefelsäurelösung von organischen oberflächen-aktiven Substanzen zwecks Beseitigung der negativen Wirkungen welche zur Herabsetzung der Entladungsströme und zur schnellen Passivierung der Elektroden führen [1—2].

Die bei der Untersuchung betreffend einige galvanischen Zellen, in denen wir als Elektrolyt mit Ultraschall behandelte Lösungen benützt haben [3—5], erhaltenen Ergebnisse leiteten uns zum Prüfen der Methoden betreffend die Erzielung von elektrischen Charakteristiken der Akkumulatoren mit Bleiplatten (Entladungsströme, Betriebszeit, Vergrösserung der Lieferungskapazität) an, zwecks deren Verbesserung durch die Wirkung des Ultraschalls auf den im Akkumulator befindlichen Elektrolyten.

2. DAS VERSUCHSVERFAHREN

Für die Untersuchung wurden kleine, statische, in der Deutschen Demokratischen Republik hergestellte, D. Quaiser—Akkumulatorzellen mit Bleiplatten benützt mit einem Leistungsvermögen von 5 Ah und in Rumänien hergestellte Le 3-Zellen mit einem Leistungsvermögen von 36 Ah.

Die in den untersuchten Zellen benützten Schwefelsäurelösungen waren vorher mit Ultraschall mittels von piezoelektrischen Generatoren mit einer Frequenz von 1 MHz (vom Type Tesla) und von 2 MHz (selbst gebaut) behandelt worden.

Die Behandlung der Lösungen mit Ultraschall wurde bei einer Temperatur von 25°C ausgeführt, welche mittels eines Ultraschallthermostaten vom Typ U 10 konstant gehalten wurde.

Die durch die kalorimetrische Methode [6–7] gemessene Stärke des Ultraschallfeldes wurde für jede ausgeführte Versuchsreihe gleichgehalten und zwar bei den Stärken der Ultraschalle:

$I_u = 1,9 \frac{W}{cm^2}$ für die Frequenz von 1 MHz und $I_u = 1 \frac{W}{cm^2}$ für die Frequenz von 2 MHz.

Die Messungen der electromotorischen Kraft wurden unter Benützung der Vergleichsmethode ausgeführt und die Spannung an den Klemmen wurde mittels elektronischer Voltmeter vom Typ URV 2 und MV 11 gemessen.

3. DIE VERSUCHSERGEBNISSE

a) Das Anwachsen der electromotorischen Kraft

Aus den ausgeführten Untersuchungen geht hervor, dass die electromotorischen Kräfte der Probezellen (mit Ultraschall behandeltem Elektrolyten) grössere Werte haben als die electromotorischen Kräfte der Bezugzellen. Das Anwachsen der electromotorischen Kräfte hängt besonders von der Dauer und Stärke der Behandlung mit Ultraschall ab.

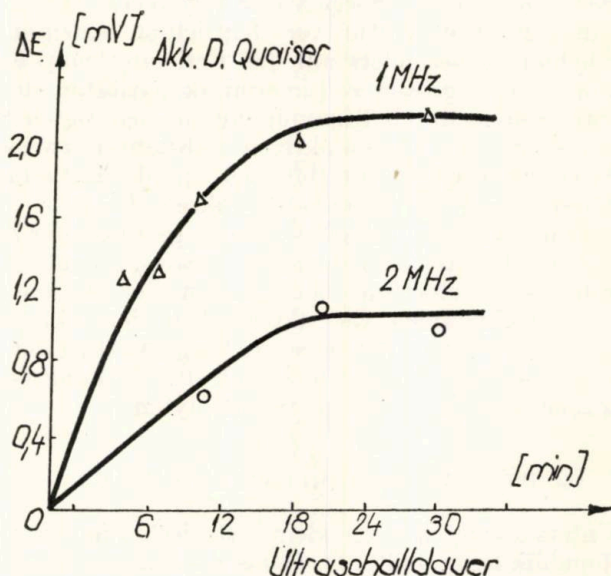


Abb. 1. Das Anwachsen der electromotorischen Kraft der Probezelle im Vergleich mitderjenigen der Bezugzelle.

In Abb. 1 ist das relative Anwachsen der elektromotorischen Kraft ΔE_r , ($\Delta E_r = \frac{E - E_0}{E_0} \cdot 100\%$, wo E und E_0 die elektromotorischen Kräfte der Probe- beziehungsweise Bezugzellen sind), in Abhängigkeit von der Dauer der Behandlung mit Ultraschall (t_u) beim D. Quaiser-Akkumulator kleinen Typs dargestellt.

Dieses Anwachsen findet bis zu einer Behandlung mit Ultraschall von 20 Minuten statt, da weiter die Tendenz konstanter Werte erhalten wird.

b. Die Verstärkung der Entladungsströme

Bei der Entladung der Zelle durch einen konstanten Widerstand, haben sowohl die Spannung als auch die Entladungsstärke (bei den Probezellen) höhere Werte als die der Bezugzelle. Die Verstärkung der Entladungsströme

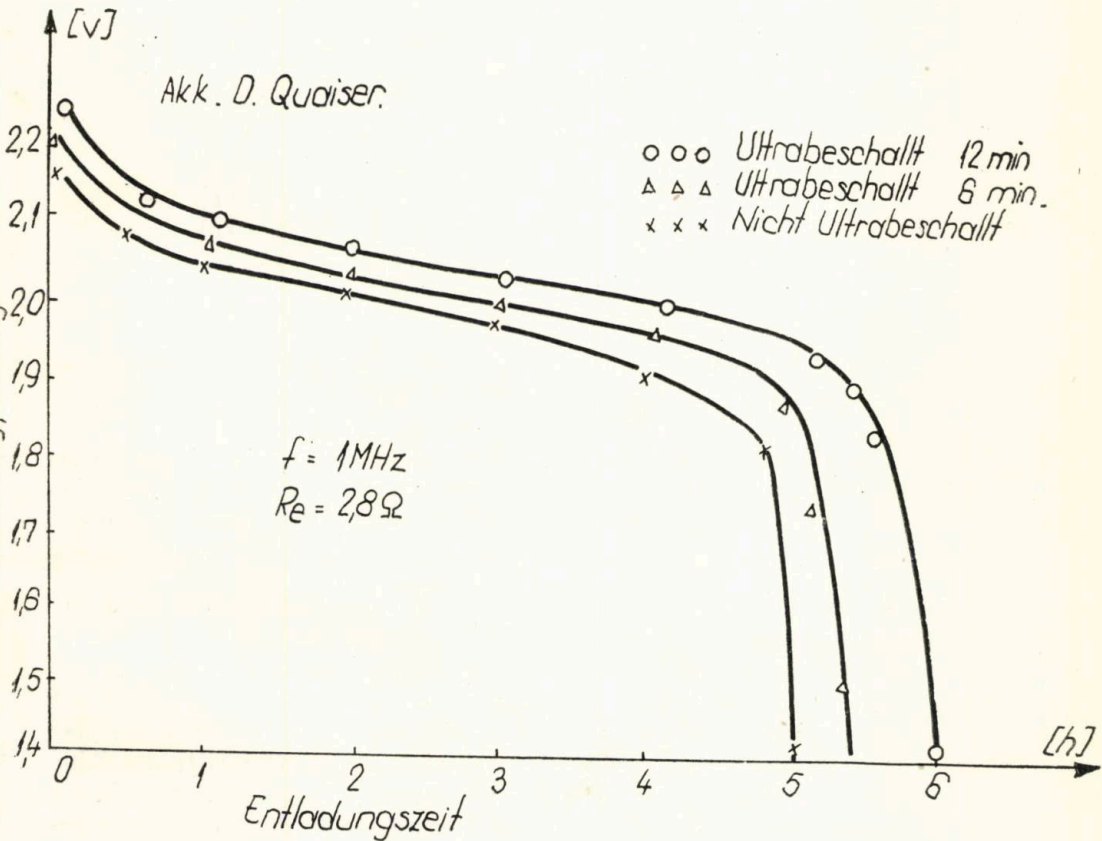


Abb. 2. Die Charakteristiken $U = f(t)$ bei der Entladung der Zellen durch konstante Widerstände von gleichem Wert.

hängt ebenfalls von der Dauer der Behandlung mit Ultraschall und von der Stärke des Ultraschallfeldes ab. Die Spannung (U) und Stärke (I) der Entladungsströme wächst bis zu einer bestimmten Dauer der Behandlung mit Ultraschall, um nachher denselben Wert beizubehalten; in Abb. 2 sind die Charakteristiken $U = f(t)$ bei der Zelle D. Quaiser bei der Entladung durch den Widerstand $R_e = 2,8 \Omega$ dargestellt, und in Abb. 3 $I = f(t)$ (bei derselben Zelle), im Falle der Behandlung der Schwefelsäurelösung mit Ultraschall.

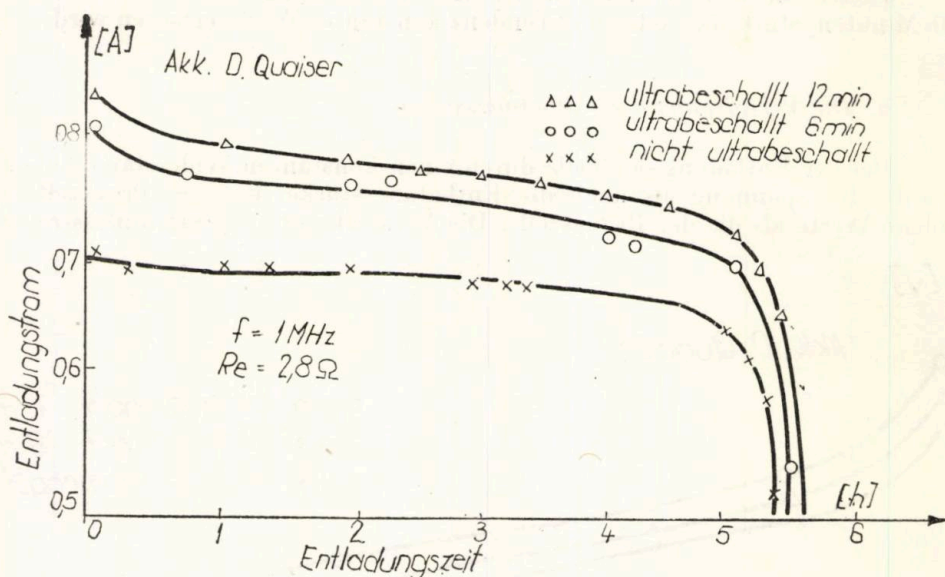


Abb. 3. Die Charakteristiken $I = f(t)$ bei der Entladung der Zellen durch konstante Widerstände von gleichem Wert.

Die Werte der Entladungsströme wachsen bis zu einer Dauer der Behandlung mit Ultraschall von 12 Minuten für 2 MHz, um nachher konstant zu bleiben. Diese Tatsache geht aus der Darstellung des relativen Anwachsens des energetischen Leistungsvermögens der D. Quaiser-Zelle ($C_r = \frac{C - C_0}{C_0} 100 \%$) hervor, welches für eine Dauer der Entladung von 5 Stunden und 15 Minuten unter den obigen Bedingungen berechnet worden ist (Abb. 4).

Bei der Entladung der Akkumulator-Zellen mit Blei durch kleine Widerstände (von der Größenordnung von Hundertstelen von Ohm), wird ein viel höheres Anwachsen erzielt als im Falle der Entladung der betreffenden Zellen durch Widerstände von der Größenordnung einiger Ohme. In der Abb. 5 sind die Charakteristiken $U = f(t)$ der statischen D. Quaiser-Zelle kleinen Typs durch den Widerstand $R_e = 0,0645 \Omega$ dargestellt; die Behandlung des Elektrolyten der Probezelle mit Ultraschall wurde bei $f = 2 \text{ MHz}$, 20 Minuten lang ausgeführt. Ähnliche Ergebnisse erhielten wir auch bei der Zelle Le 3; in

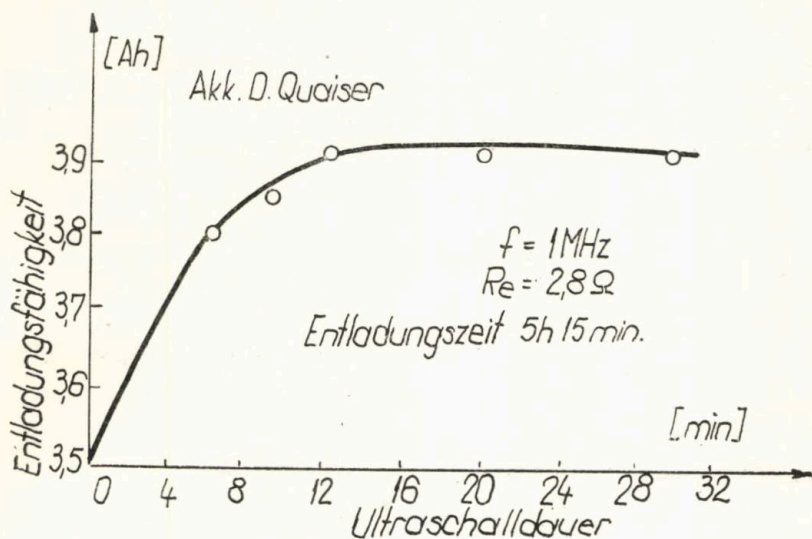


Abb. 4. Das Anwachsen des Leistungsvermögens in Abhängigkeit von der Dauer der Behandlung mit Ultraschall.

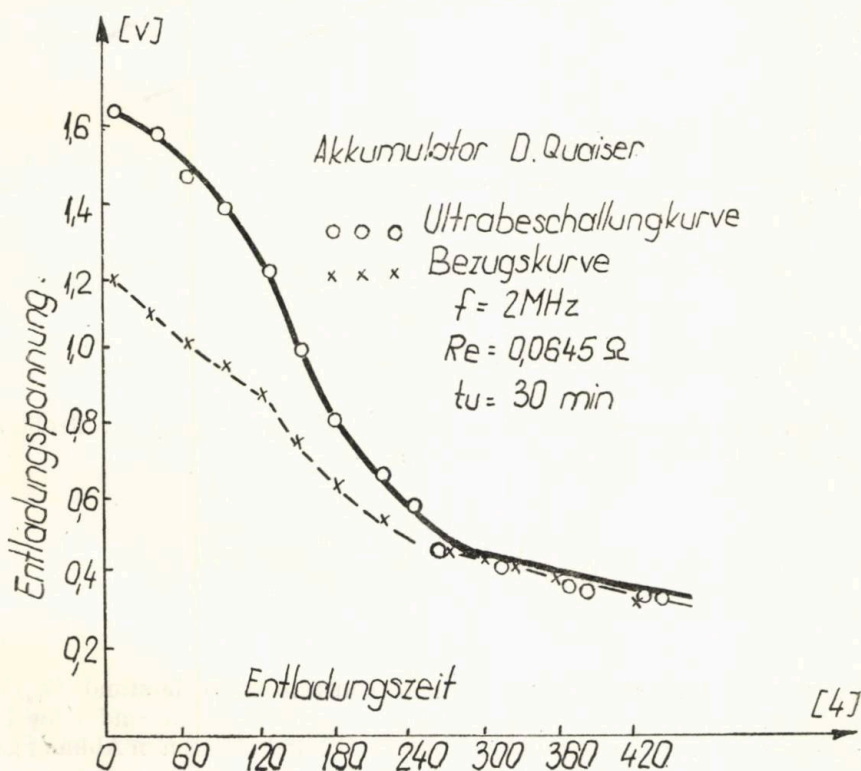


Abb. 5. Die Charakteristik $U = f(t)$, im Falle der Entladung der Zelle durch sehr kleine Widerstände.

Abb. 6 sind dieselben Charakteristiken bei der Entladung durch $R_e = 0,7 \Omega$ dargestellt. Die Behandlung des Elektrolyten der Probezelle wurde bei $f = 1$ MHz und einer Dauer von 6 Minuten ausgeführt.

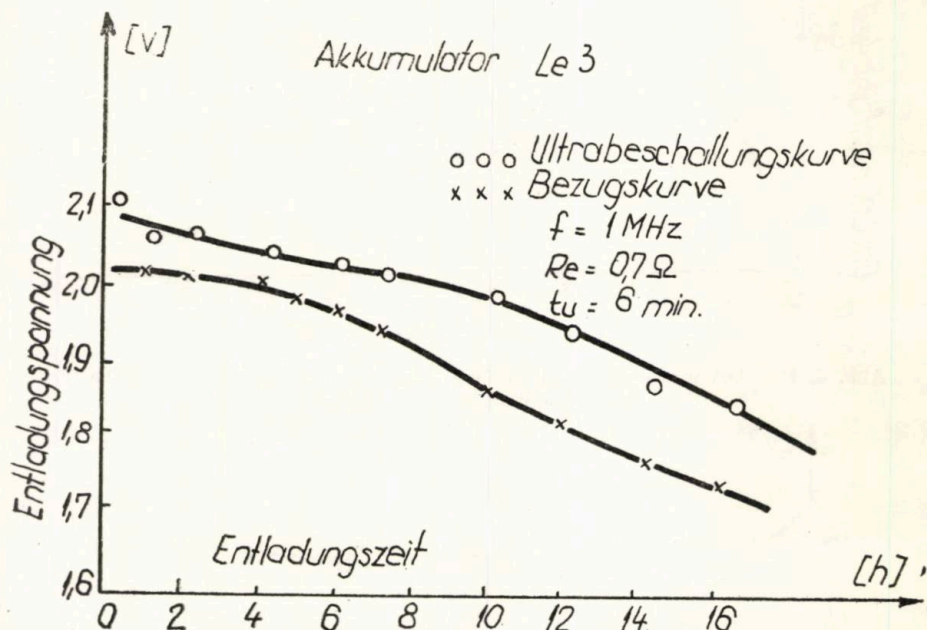


Abb. 6. Die Charakteristik $U = f(t)$ bei Akkumulatoren mit sehr grossem Leistungsvermögen.

c) Die Erhöhung der Entladungsfähigkeit

Wenn man den relativen Wert der Entladungsfähigkeit der Probezelle im Vergleich zur Bezugzelle wie folgt ausdrückt

$$C_r = \frac{\int_0^t I(t) dt - \int_0^t I_0(t) dt}{\int_0^t I_0(t) dt}, \quad (1)$$

wo I_0 die Entladungsstärke durch einen konstanten Widerstand (R_e) der Probezelle bedeutet, I_0 die Entladungsstärke der Bezugzelle und t die Entladungsdauer der Zelle durch den Widerstand (R_e) und man ihn in Abhängigkeit von der Dauer der Behandlung mit Ultraschall darstellt, so bemerken wir, dass der relative Wert des Leistungsvermögens der Akkumulatorzelle mit der Dauer der Behandlung mit Ultraschall bis zu den mehr oben angegebenen

Grenzwerten (Abb. 4) anwächst, um nachher konstant zu bleiben. Das höchste erzielte relative Anwachsen gelangte bis zu 23,9% im Falle der Entladung der Zelle durch Widerstände von der Grössenordnung einiger Ohme ($2,8\Omega$) und bis zu 40–42% bei der Entladung durch $R_e = 0,0645\Omega$.

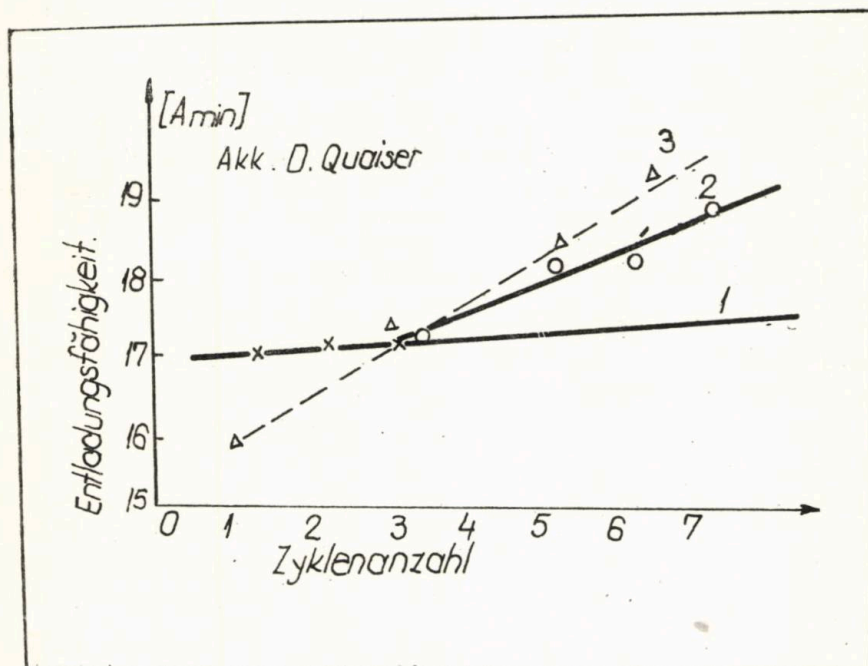


Abb. 7. Die Veränderung des Leistungsvermögens in Abhängigkeit von der Anzahl der Folgen.

Die Entladungsfähigkeit der Akkumulatorzelle erhöht sich desgleichen mit der Anzahl der Entladungsfolgen. In Abb. 7 ist diese Erhöhung für die D. Quaiser-Zelle dargestellt: a) für den Fall in dem die elektrolytische Lösung aus der Zelle nicht mit Ultraschall behandelt wurde (Linie 1), b) in dem sie nach der Bildung des Akkumulators mit Ultraschall behandelt wurde (Linie 2), c) in dem sie vor der Bildung mit Ultraschall behandelt wurde (Linie 3). Es wird festgestellt, dass die besten Ergebnisse im Falle einer Behandlung der Lösung mit Ultraschall vor der Bildung des Akkumulators erzielt werden.

d) Die Verlängerung der optimalen Betriebsdauer

Bei den Akkumulatorzellen deren Lösungen mit Ultraschall behandelt wurden, wächst die Entladungsdauer bis zur zugelassenen Mindestspannung (die Betriebsdauer t_x) im Vergleich zur Betriebsdauer der Bezugzelle.

Bei der D. Quaiser—Akkumulatorzelle kleinen Typs mit dem 5 Minuten lang mit Ultraschall bei einer Frequenz von 1 MHz behandelten Elektrolyten, verlängert sich im Falle der Entladung der Zelle durch den Widerstand von $2,8 \Omega$ die Betriebsdauer bis zur Mindestspannung von 1,8 V um eine Stunde, also um 25 % der normalen Entladungsdauer der Zelle. Für die Le 3—Zelle mit der unter gleichen Bedingungen mit Ultraschall behandelten Lösung, erhält man bei der Entladung durch $R_e = 0,7 \Omega$ eine Verlängerung der Entladungsdauer um 5 Stunde, also um 38% länger als die in Betracht gezogene Dauer der Bezugzelle.

Die relative Veränderung der Entladungsspannungen der Zelle in Abhängigkeit von der Dauer der Behandlung mit Ultraschall wird in Form von unsymmetrischen Kurven dargestellt, deren Höchstwerte sich zugleich mit der Verlängerung der Dauer der Behandlung der Zelle mit Ultraschall gegen höhere Werte der Betriebsdauer verschieben.

In Abb. 8 sind die Charakteristiken $U_r = f(t_u)$ für die D. Quaiser—Akkumulatorzellen dargestellt, $U_r = \frac{U - U_0}{U_0}$, wo U und U_0 die Entladungsspannungen der Probe — respektive Bezugzellen bedeuten und t_u die Behandlungsdauer mit Ultraschall des Elektrolyten der Probezellen.

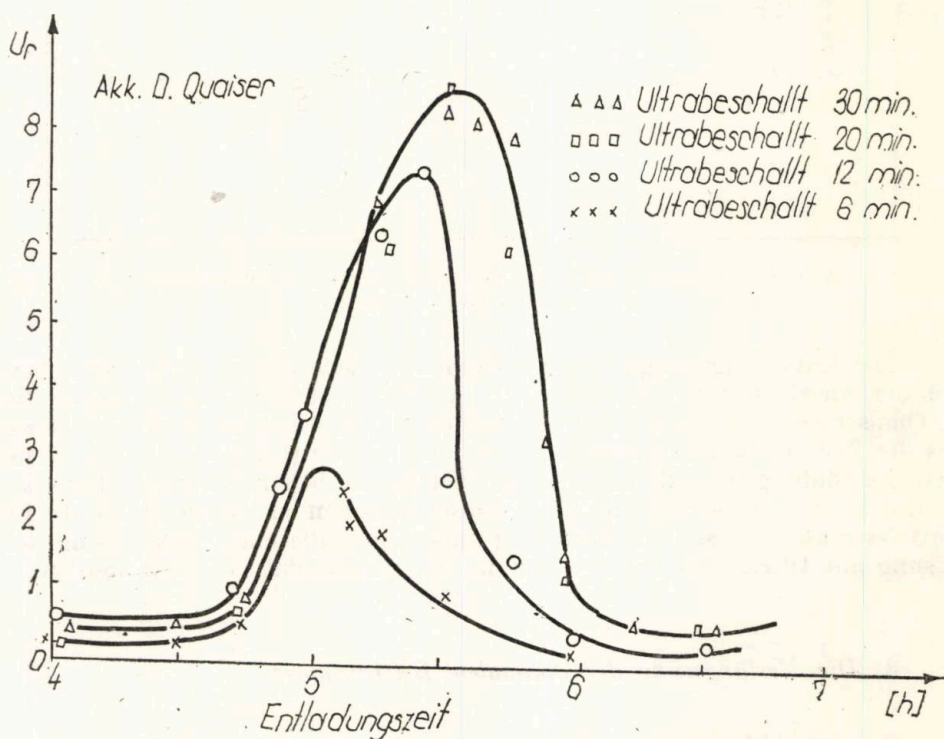


Abb. 8. Das relative Anwachsen der Entladungsspannung für verschiedene Behandlungszeiten mit Ultraschall.

Die durchschnittliche Betriebsdauer einer Zelle bis zu einer bestimmten Mindestgrenzspannung (E_x), die von uns optimale durchschnittliche Zeit genannt wird, kann berechnet werden indem man die Lage des Schwerpunktes der Kurven der Veränderung der Entladungsspannung (Abb. 8) in Abhängigkeit von der Dauer der Behandlung mit Ultraschall [8—9] gemäss der Beziehung

$$\bar{t}_x = \frac{\int_0^\infty t U_r(t) dt}{\int_0^\infty U_r(t) dt} \quad (2)$$

berechnet, wo t die Entladungsdauer der untersuchten Zellen und U_r die relative Veränderung der Entladungsspannung der Probezellen im Vergleich zur Entladungsspannung der Bezugzelle bedeuten.

In unserem Falle kann $\bar{t}_x$ für einen konstanten Entladungswiderstand aus der Beziehung

$$\bar{t}_x = \frac{\sum_{i=1}^n t_i U_{ri}(t)}{\sum_{i=1}^n U_{ri}(t)} \quad (3)$$

berechnet werden.

Wenn man die Funktion $E_x = f(t_u)$, Abb. 9, graphisch darstellt so stellt man fest, dass die durchschnittliche optimale Zeit bis zu 12 Minuten Behandlung mit Ultraschall sich verlängert (für beide benutzte Frequenzen), um nachher für eine beliebige Dauer der Behandlung mit Ultraschall konstant zu bleiben.

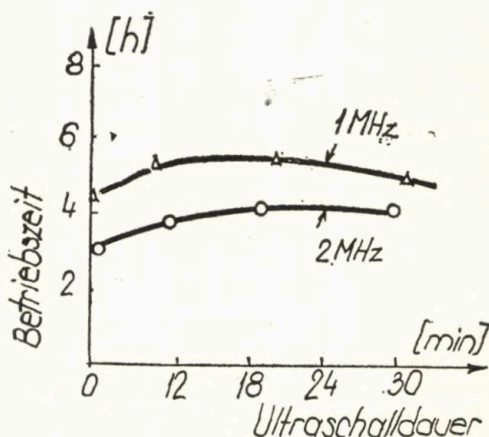


Abb. 9. Die Verlängerung der Betriebszeit der Zelle in Abhängigkeit von der Behandlung mit Ultraschall.

4. DIE BESPRECHUNG DER VERSUCHSERGEBNISSE

a) Die Veränderung der Aktivität der Schwefelsäurelösung durch die Ultraschallwellen

Die Ultraschallwellen üben auf die Elektrolytlösungen Wirkungen aus die zur Beschleunigung der chemischen Reaktionen führen, bezüglich zur Veränderung der elektrischen Leitfähigkeit, der Beweglichkeit der Ionen, der Viskosität [10–13].

Die Gleichung des Transports der elektrischen Ladung aus einer galvanischen Zelle mit homogenem Elektrolyten hat den Ausdruck

$$\vec{I} = -\gamma \vec{\text{grad}} \cdot V \quad (4)$$

wo

$$\gamma = \sum_{i=1}^n (c_i, U_i, z_i, F). \quad (5)$$

c_i ist die Konzentration der ionischen Arten aus der Lösung, U_i die Spannung an den Klemmen, z_i die Wertigkeit, F die Zahl Faradays, V das betreffende Potential.

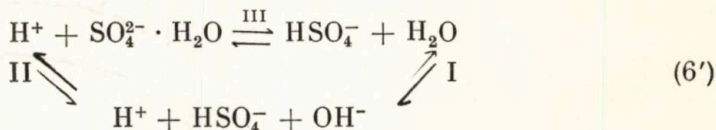
Wenn die Wirkung der Ultraschallwellen eine Erhöhung der Leitfähigkeit der elektrolytischen Lösung (γ) verursacht, wird natürlich auch die Stärke des Entladungsstroms sich gemäss der Beziehung (4) erhöhen. Diese Behauptung wurde durch Versuche geprüft, so wie dies aus den Abbildungen 2,3,4,5 und 6 hervorgeht.

Der Grund dieser von uns bei den Akkumulatorzellen festgestellten Verstärkung des Entladungsstromes wird von der Intensivierung der Oxydierungs- und Reduktionsreaktionen dank der Aufspaltung der Wassermoleküle in Radikale und Ionen



gebildet.

Diese Aufspaltung der Moleküle kann zu einer Reihe von Möglichkeiten für die Abwicklung von Reaktionen (14) der Form



führen.

Die Abwicklungen der Reaktionen, besonders der in III (6') angeführten, haben als Wirkung die Veränderung der elektrischen Charakteristiken der Zellen und zwar die Verstärkung der Strom erzeugenden Vorgänge welche sich durch elektromotorische Kräfte, Intensitäten, Entladungsspannungen und energetisches Leistungsvermögen grösserer Werte kundtun.

Die Akkumulatorzelle liefert die elektrische Energie infolge der chemischen Vorgänge die im inneren Kreislauf stattfinden. Die elektromotorische Kraft erscheint als ein Mass der umkehrbaren Arbeit und ist an den Reaktionsvorgang gebunden der den Strom durch die Beziehung von Gibbs und Helmholtz erzeugt:

$$E = -\frac{\Delta H}{zF} + T \left(\frac{\partial E}{\partial T} \right)_p \quad (7)$$

wo H die Reaktionsenthalpie des Strom erzeugenden Vorgangs darstellt.

Die relative Erhöhung der Enthalpie $\left(\Delta H_r = \frac{\Delta H - \Delta H_0}{\Delta H_0} \cdot 100\% \right)$, wo ΔH und ΔH_0 die Enthalpien der Probe — und Bezugszellen sind) in Abhängigkeit von der Dauer der Behandlung mit Ultraschall, findet nach einer Parabel (Abb. 10) statt:

$$t_u = K_{\Delta H} \Delta H_r^2 \quad (8)$$

$$\Delta H_r = \frac{\left[T \left(\frac{\partial E_u}{\partial T} \right)_p - E_u \right] - \left[T \left(\frac{\partial E}{\partial T} \right)_p - E \right]}{T \left(\frac{\partial E}{\partial T} \right)_p - E} \quad (9)$$

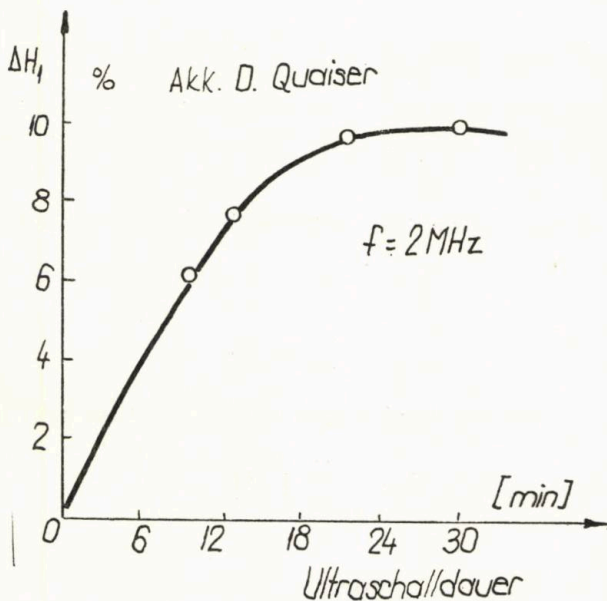


Abb. 10. Die relative Veränderung der Reaktionsenthalpie in Abhängigkeit von der Dauer der Behandlung mit Ultraschall.

E_u ist die elektromotorische Kraft der Probezelle, E die elektromotorische Kraft der Bezugzelle und $K_{\Delta H}$ eine Konstante.

Auf Grund unserer Versuche, bei welcher Gelegenheit die Bestimmungen bei derselben (konstanten) Temperatur ausgeführt wurden,

$$\frac{\partial E_u}{\partial T} \approx \frac{\partial E}{\partial T}$$

und der Beziehung (9), kann man noch

$$\Delta H_r = \frac{E - E_u}{T \left(\frac{\partial E}{\partial T} \right)_p - E} \quad (10)$$

schreiben.

Die elektromotorische Kraft einer galvanischen Zelle kann in Abhängigkeit von der Aktivität der Bestandteile des Elektrolyten (a_i), der am Bildungsvorgang des elektrischen Stromes teilnimmt, in folgender Form ausgedrückt werden:

$$E = E_0 - \frac{RT}{zF} \ln \Pi a_i^{\alpha_i \nu_i} \quad (11)$$

wo E_0 die elektromotorische Standardkraft, α_i ein Koeffizient mit dem Wert (+1) für die Endprodukte und (-1) für die Anfangsprodukte, und ν_i die stoechiometrischen Koeffizienten aus der Strom erzeugenden chemischen Reaktion sind.



Wenn man einesteils (12) berücksichtigt und die Tatsache, dass für unsere Versuche ($t = 22^\circ\text{C}$), haben wir $T \left(\frac{\partial E}{\partial T} \right) \approx 0,1$, was in der Beziehung (10)

vernachlässigt werden kann, und wenn man das Verhältnis $\frac{a_{\text{H}_2\text{SO}_4}}{a_{\text{H}_2\text{O}}} \approx 1$, [1] berücksichtigt, so kann die Beziehung (10) in folgender Form geschrieben werden

$$\Delta H_r = \frac{RT}{zFE_0} \ln \frac{a'_{\text{H}_2\text{SO}_4}}{a'_{\text{H}_2\text{O}}} \quad (13)$$

Wenn man in (8) den Ausdruck aus (13) ersetzt, so erhalten wir

$$t_u = K_{\Delta H} \left(\frac{RT}{zFE_0} \right)^2 \ln \left(\frac{a'_{\text{H}_2\text{SO}_4}}{a'_{\text{H}_2\text{O}}} \right)^2 \quad (14)$$

wo

$$\frac{a'_{\text{H}_2\text{SO}_4}}{a'_{\text{H}_2\text{O}}} = e^{K' \sqrt{t_u}} \quad (15)$$

$$K' = \frac{zFE_0}{R_t \sqrt{K_{\Delta H}}} > 0.$$

Aus Beziehung (15) wird festgestellt, dass

$$a'_{H_2SO_4} > a'_{H_2O} \quad (16)$$

was die Tatsache hervorhebt, dass die Wirkung des Ultraschalls auf die Schwefelsäure vorherrschend ist (im Vergleich zum Wasser).

b) Die Intensivierung des Diffusionsvorgangs

Die durch Ultraschall intensivierten chemischen Reaktionen tragen zur Intensivierung des Diffusionsvorgangs bei. Wenn man die Strom erzeugende chemische Reaktion (12) berücksichtigt, so kann man annehmen, dass zwischen der gelieferten Elektrizitätsmenge und der veränderten Schwefelsäuremenge eine unmittelbare Proportionalität besteht [2]. Wenn man dies berücksichtigt, können wir die Veränderungsgeschwindigkeit der Schwefelsäure $\left(\frac{dm}{dt}\right)$ in Abhängigkeit von der gelieferten Elektrizitätsmenge aus der Zelle $C(t)$ folgendermassen ausdrücken:

$$\frac{dm}{dt} = KC(t). \quad (17)$$

K ist eine Proportionalitätskonstante.

Die für die Entladungsdauer t der Zelle verbrauchte Schwefelsäuremenge ist dann durch die Beziehung

$$m = K \int_0^t C(t) dt = K \int_0^t I(t) t dt \quad (18)$$

gegeben, wo m die für die Lieferung der Elektrizitätsmenge in der Zeit t veränderte Schwefelsäuremenge bedeutet und I die Stärke des Entladungstromes aus der Zelle.

Für den konstanten Entladungswiderstand ($R_e = \text{const.}$) kann man die Beziehung (18) wie folgt schreiben:

$$m = \frac{Kt^2}{2n} \sum_{i=1}^n I_i \quad (19)$$

Wenn man die Beziehung (18) berücksichtigt, so kann man die Intensivierung des Diffusionsvorgangs, der in der Akkumulatorzelle stattfindet, beweisen. Diese Intensivierung hängt von der transformierten Schwefelsäuremenge ab, bezüglich von der Stärke des Entladungstromes.

Auf Grund der Versuchsergebnisse stellt man fest, dass die Entladungsintensität (I) der Zellen mit dem mit Ultraschall behandelten Elektrolyten grösser ist als die Entladungsintensität der Bezugzelle.

Wenn man die Beziehung (19) berücksichtigt, so kann man

$$\frac{m}{m_0} \equiv \frac{I}{I_0} \quad (20)$$

schreiben.

Da $I > I_0$, geht hervor, dass auch $m > m_0$, also dass die Schwefelsäuremenge die sich umsetzt der bei Probezelle grösser ist, was die Verstärkung des Diffusionsvorgangs der Akkumulatorzelle infolge der Wirkung der Ultraschalle hervorhebt. Diese Verstärkung steigert sich mit der Dauer der Behandlung mit Ultraschall (Tabelle 1).

TABELLE 1

Die Dauer der Behandlung mit Ultraschall	0	6	9	12	20	30	Bemerk.
$\frac{I}{I_0}$	1,00	1,13	1,14	1,15	1,15	1,16	$f = 1 \text{ MHz}$

c) Veränderungen im Verlauf der Strom erzeugenden Vorgänge

Infolge der Wirkungen die die Ultraschalle auf die in der Akkumulatorzelle benützten Schwefelsäurelösungen ausüben, ändern sich manche Vorgänge die bei der Ladung und Entladung des Akkumulators stattfinden.

Der von Dasoean [1] unter den Bedingungen einer Zelle mit nicht mit Ultraschall behandelter Lösung dargestellte Mechanismus dieser Vorgänge wurde verändert, indem man die vom Ultraschall im Elektrolyten hervorgerufene Wirkung berücksichtigte. Die für den Ionisierungsvorgang verbrauchte elektrische Energie (im Falle der Bezugzellen) wird verfügbar um die Veränderungen zu verstärken die während der Ladung (Abb. 11 b) oder der Entladung (Abb. 12 b) auftreten. In den Abbildungen 11 a und 12 a ist der von Dasoean benutzte Ladungs- und Entladungsmechanismus des Akkumulators mit Bleiplatten dargestellt.

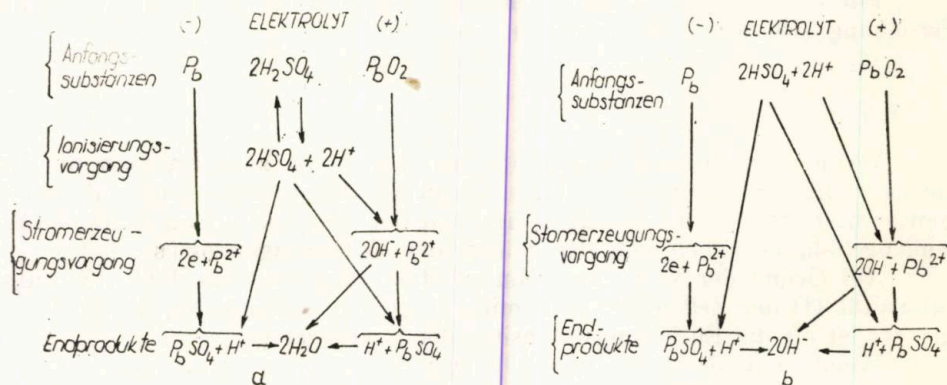


Abb. 11. Der Lademechanismus des Akkumulators
a) bei der Zelle deren Lösung nicht mit Ultraschall behandelt wurde
b) bei der Zelle deren Lösung mit Ultraschall behandelt wurde.

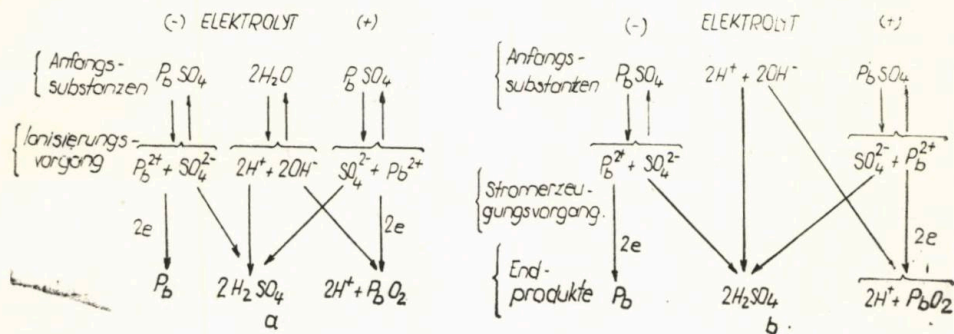


Abb. 12. Der Entlademechanismus des Akkumulators:
a) bei der Bezugzelle
b) bei der Probezelle.

5. SCHLUSSFOLGERUNGEN

Die Untersuchung der elektrischen Charakteristiken der Akkumulatoren mit Bleiplatten mit Ultraschall behandelten H₂SO₄ Lösungen führt zu folgenden Schlussfolgerungen:

1. Die in den Zellen mit Elektrolyten die mit Ultraschall behandelt wurden erzeugten Entladungsströme haben grössere Werte als die entsprechenden Werte aus den Bezugszellen.

2. Die Entladungsfähigkeiten der Zellen durch konstante Widerstände von der Grössenordnung einiger Ohme erhöhen sich in Abhängigkeit von der Dauer der Behandlung mit Ultraschall. Diese Erhöhungen sind grösser im Falle der Entladung der Zellen durch sehr kleine Widerstände (von der Grössenordnung einiger Hundertstel von Ohm).

3. Die Wirkung des Ultraschalls auf die in der Akkumulatorzelle benützten Schwefelsäurelösungen verstärkt die Strom erzeugenden Vorgänge. Dieses verdanken wir der Tatsache, dass die im Falle der Bezugszellen für den Ionisierungsvorgang benützte Energie jetzt an der Verstärkung des elektrischen Stromes (aus den Probezellen) teilnimmt.

4. Diese Vorgänge führen zur Erhöhung des Lieferungsvermögens der Zellen und zur Verlängerung der Betriebsdauer der Akkumulatoren, eine Tatsache die von sofortigem praktischem Interesse sein kann.

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ENERGETICAL CONSIDERATIONS IN E.E.G. INTERPRETATIONS

by ION BĂIANU

ABSTRACT

The interpretation of E.E.G is still contradictory due to a lack of knowledge concerning the mechanisms through which the intrinsic rhythms of the brain are generated. The paper presents an electric model of neural net which has oscillatory properties. On the basis of this model some evaluations of the energy implied in the oscillations of the net are given. Then, the conclusions of the model are used to discuss some properties of particular nets.

1. INTRODUCTION

From the first experiments of Berger (1), E.E.G. — recordings continued to be fairly complex and difficult to understand. A computation of the energy involved in the electrical activity of the brain could be a fruitful approach to the understanding and interpretation of E.E.G. Any computation of this type cannot avoid structural considerations concerning the underlying neural net. The, one has to consider the transformations of the nerve impulse at the synapse levels and the interactions among the fibers of the same nerve. From a structural point of view the models of neural nets can be classified into discrete and continuous. The underlying structures of discrete models are algebraic, while the structures appearing in continuous models are topologic. A more complex model would involve both algebraic and topological structures. In such a model one has to be able to connect algebraic structures with topological ones. Algebraic Topology, the Theory of Categories and Functors and Algebraic Geometry are three related mathematical theories which deal with such a connection of algebraic structures with topological ones. On the other hand, physical models, although being based on such structures, have to introduce analytic functions which predict the behaviour of particular systems in certain determined conditions. These conditions are appropriately chosen such as to allow one to get a numerical solution of the problem. In connection with it let us recall some of the transformations of nerve impulses at the synapse levels. These are: summation, integration, differentiation, amplifications and filtering. All these transformations will be first regarded as abstract mathematical functions, and then a physical model will be derived on the basis of the underlying categorical structure.

2. A CATEGORICAL MODEL OF NEURAL NETS.

Models of neural nets were first represented abstractly by Nicholas Rashevsky (2). Our model is a further abstraction and it is continued with a realization of this abstract model.

Let us consider a unit of a neural net which possesses the structure shown in Fig. 1

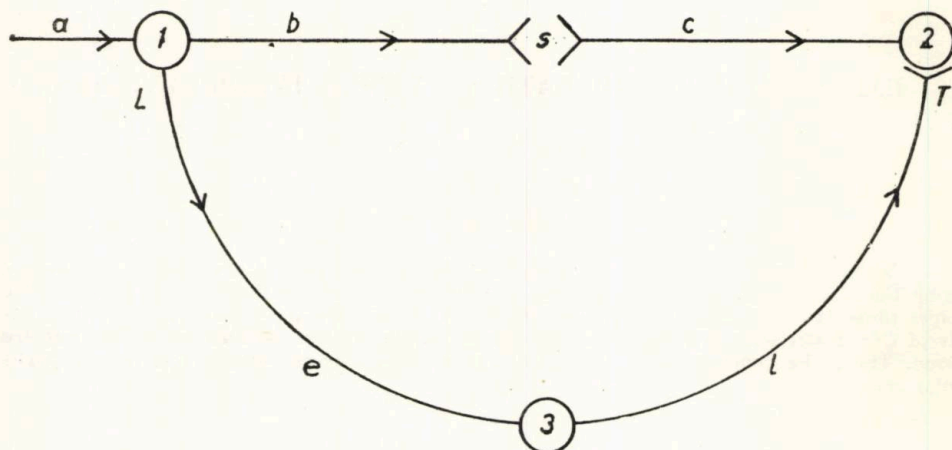


Fig. 1 A cycle in a neural net

Legend: 1, 2 and 3 are neurons and *a*, *b*, *c*, *d*, *e*, and *f* are nerve impulses on the corresponding neural paths: *L*, *T* and *S* are synapses among neurons 1, 2 and 3, correspondingly.

Also, let us introduce the following notations:

$$1 = \{f, f'\}, 2 = \{g, g'\}, a = A, b = B, c = C, d = D,$$

$1 = F, L = i, T = j, S = k$. With these notations Fig. 1 can be represented by the categorical diagram, (see Fig. 2). *A, B, C, D, E* and *F* will be called *objects* and they represent nerve impulses on the corresponding neural paths. Letters *f, g, h, i, j* and *k* will be called *morphisms* and they will represent transformations of nerve impulses.

Those transformations of nerve impulses which are due to some local variations in fibers' activities will be denoted by i_A, i_B, i_C, i_D , and i_L , respectively. The identity transformations are defined as transformation which leave unchanged any nerve impulse at the level where it is localized. It may be easily checked that the above introduced *objects* and *morphisms* form a *category*, that is, a class together with a partially defined law of composition. (For further mathematical details the reader is referred to (3), (4), (5), or (7). Let us recall that the objects of this category are nerve impulses and its morphisms are transformations of nerve impulses. The categorical approach allows one to consider both algebraic and topological aspects of neural nets. However, we shall here

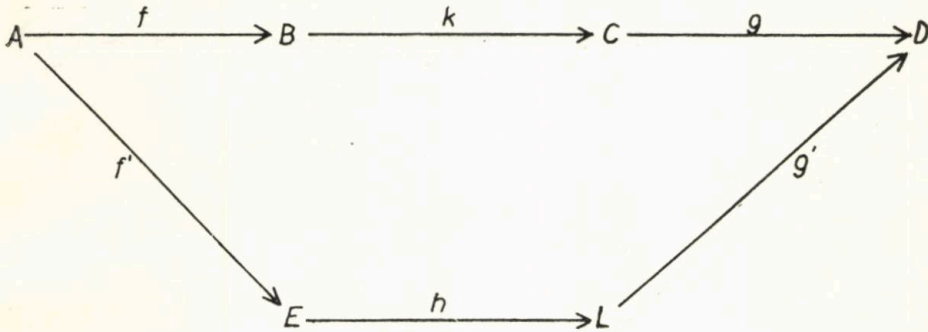


Fig. 2. A categorical diagram of a cycle in a neural net.

restrict ourselves to the study of structures of oscillatory neural nets. The simplest example of an oscillating neural net would be $A \xrightarrow{f} B$ with $f = \sin$ or $\cos$. However, there is no neuron exhibiting these properties, and this situation does not seem to be actually realized. The minimal diagram of a net which could 'oscillate' is the following graph.

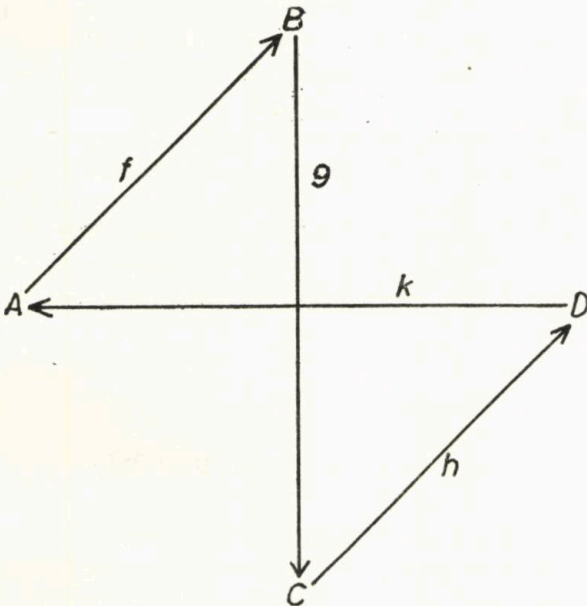


Diagram 1.

Its corresponding neural is shown in Fig. 3.

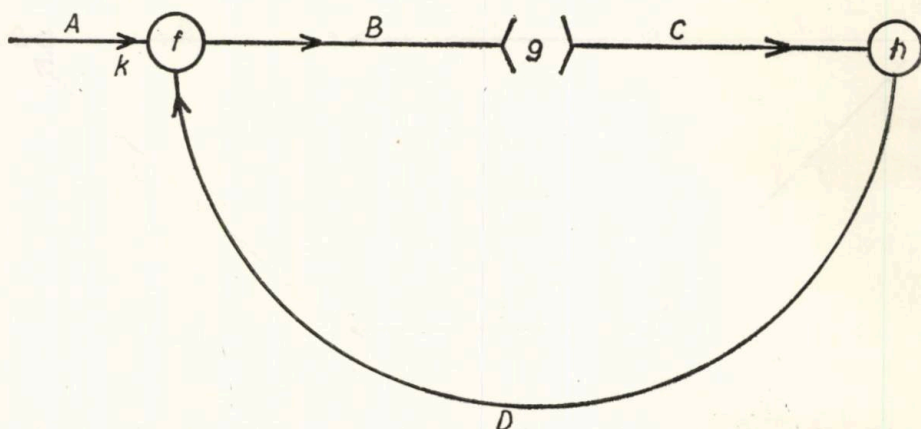


Fig. 3. The minimal oscillatory neural netz (neural oscillator)

All diagrams of nets which contain the above diagram could represent oscillatory neural nets. The pattern represented in Fig. 3 will be called *neural oscillator*. The diagram of a neuronal oscillator actually represents an oscillator if and only if all its morphisms are composable and if f plays role of a discriminator, (that is, if f is able to 'compare' the level of the input with some data which are stored in its 'memory'.) The diagrams corresponding to more complex oscillatory neural nets can be constructed according to some rules which can be easily derived through combinatorial computations. Thus, one can easily compute the maximum number of allowed combinations of neurons which result in an oscillatory neural net. Also, on the basis of our diagrams one can determine the maximum number of neural oscillators which may be formed with a fixed number N of neurons. We shall not enter into details of such a computation. Instead of it we shall take the number N of neural oscillators as given and this number will be used in our computations.

3. THE PHYSICAL MODEL

The basic assumption of our model is that the effects due to couplings through mutual induction can be neglected. In this case the energy dissipated by the oscillating neural net is the sum of the energies of the n non-interacting neural oscillators:

$$W = \sum_{i=1}^n w_i$$

with w_i being the energies of individual uncoupled oscillators. If the net has nodes which are common to v neural oscillators, then one has to consider only once the energy dissipated at each common node. That is, one has that

$$W' = \sum_{i=1}^n [w_i - (v - 1) g_i(v, n_0)]$$

with $g_i(v, n_0)$ being a function which depends on the dissipating properties of the common nodes. Now, if all neural oscillators are analogised with harmonic oscillators, then one finds that the expressions of energy becomes

$$W_0 = 1/2 \sum_{i=1}^n [k_i A_i^2 - 2(v - 1) g'_i(v, n_0)],$$

with A_i being the amplitudes of oscillation of the harmonic oscillators, and with $k_i = 2\pi^2 c_i z_i v_{oi}^2$. In this last expression c_i is the number of elements of each circuit, z_i is a constant which characterizes the dissipating properties of the i -th element of the circuit, and v_{oi} are the frequencies of oscillation of harmonic oscillators. Then, the power dissipated by the whole net is

$$P = \frac{\sum_{i=1}^n [c_i z_i v_{oi}^2 A_i^2 - (v - 1) g'_i(v, n_0)]}{\tau} \quad (1)$$

with τ being an interval of time when all oscillators are functioning. However the oscillations of neural circuits which are recorded as E.E.G. seem to be of the relaxation type and they are undamped (1). For each individual neural oscillator one can consider that $v_i = 1/A_i$, since the whole set behaves as a non-linear system. Also, the simplest assumption concerning z_i is that the dissipating properties of each element depend linearly on the corresponding frequencies. With this additional assumption eq. (1) becomes

$$W_0 = \sum_{i=1}^n [c_i v_{oi} - (v - 1) g'_i(v, n_0)] \quad (2)$$

It may be seen from this expression that the energy depends linearly on the frequencies of oscillation of the neural oscillators. This conclusion seems to be supported by some recent data concerning E.E.G. recordings in epilepsy (personal communication of Dr. Ralph Sherman from the J. M. Richards Laboratory of Biophysics, Michigan). Thus, the rythms observed after a glucose dose conform to this conclusion since the higher frequency oscillations dominate the others subsequent to the administration of glucose. However, the experiments do not allow one by now to establish the exact relation between energy and frequencies of oscillation.

4. TWO PARTICULAR REALIZATIONS OF THE PHYSICAL MODEL

A direct particular realization is obtained if one considers the Hodgkin-Huxley model of a neuron. If a is the radius of a nervous fiber, R —its specific resistance, C —the capacity of the membrane, U —the resting state potential, and V —the action potential, then the energy which is dissipated by a single fiber is

$$w = 1/4 \frac{(V - U)^2}{\sqrt{1/C^2\omega^2 + a^2/4R^2}} \quad (3)$$

The energy dissipated by the n neural oscillators is now

$$W' = 1/4 \sum_{i=1}^n \left[\frac{(V_i - U_i)^2 z_i c_i \cdot v_{oi}}{\sqrt{(a^2/R_i^2) \cdot C_i^2 \omega_i^2 + v_{oi}^2 + 1}} - (v - 1)g'(v, n_0) \right] \quad (4)$$

Now, let us consider the second realization of our model on the basis of the Ling Wey's model. The current J through the nerve membrane is in this case $J = b^2 \sin kv$, with V being the membrane potential and with b^2 being a constant which has the dimensions of a conductance. The power dissipated in this case by a circuit element is:

$$w/\tau = 4b^2 \cdot \int_{V_-}^{V_+} (\sin kV) dV \simeq (4b^2/k) (2\bar{V} - U) \bar{V} \quad (5)$$

with $\bar{V}$ being an average potential, (approximately half of the absolute value of the action potential). It shows that the dissipated power depends on the temperature since b^2 depends on the temperature of the circuit element. This conclusion could be subject to experimental verification. Expression (5) above apparently contradicts eq. (2) and (4). Thus, it results from (5) that the energy dissipated by the net would be

$$W'' = \sum_{i=1}^n (2/K) b_i^2 (2\bar{V}_i - U_i) \bar{V}_i - (v - 1) g'_i(v, n_0) \quad (6)$$

and this expression does not depend, at least explicitly, on the frequencies of oscillation. It is rather difficult to find an experimental model to establish firmly which of the two realizations is correct. However, we mentioned on p.5, a few experimental data which seem to indicate that the first realization is more likely to be valid.

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COMPUTATION CRITERIA FOR AN OPTIMAL BIOMACROMOLECULAR MODEL

LIVIA IONESCU and ION C. PETREA

ABSTRACT

Some criteria are established for the selection and computation of an optimal biomacromolecular model, by taking into consideration two conformation types, affected by three preferential characteristic parameters.

RÉSUMÉ

On a établi quelques critères pour la sélection et la calcul du modèle macromoléculaire optimal, par la considération de deux types de conformations, affectées par trois paramètres caractéristiques préférentiels.

INTRODUCTION

The structure and the biological functions of the biopolymer systems form the object of recent preoccupations concerning the physico-chemical characteristics of the macromolecules [1], [2].

The studies made on the morphological, structural and functional peculiarities of the biomacromolecular systems imply associations and statistical averages that show both the polydispersity and the cooperation of the various constitutive entities.

The statistical interpretation of the connexion mechanisms of the principal physico-structural parameters helps to elucidate some essential aspects of the determinism specific of the biopolymer systems, able to transmit, by code, through the agency of the live cell, the genetic message. At present, it is well known that the biological processes comprize the transfer of molecules, ions, energy within a context of structure similitudes and textures that import to the biomacromolecular system an evolution programmed according to a given capacity of information.

The qualitative premises of the information amount stocking, biologically codifiable in the existence of the live cell, from its appearance to its death, cannot be dissociated from the geometry, i.e. from the dimensions and the structure complexity of the biomacromolecular system or from the different series of

parameters which characterize it from the physical, chemical, physico-chemical standpoint. The functions of the codified transcription of the cell stocked informations offer an evidence pre-eminently mediated by the biological macromolecules, typically represented from this standpoint by the nucleic acids. Should the biological systems lack a proper macromolecular structure, the prevailing thermodynamic state would be inconsistent with the stationary states and then an equilibrium tendency would appear causing the disorganization of the vital process.

The selection optimizing of a biomacromolecular model in case of the existence of several conformers, distinctly described by parameters preferentially associated with one or another conformation of the given system, constitutes a problem of stringent actuality and scientific importance [3], [4].

Hereafter, some criteria are established for the selection and computation of a biomacromolecular model, concomitantly affected by two types of conformations and three characteristic parameters.

ESTIMATIVE CRITERIA FOR BIOMACROMOLECULE MODELLING

The construction of a suitable biomacromolecular model implies several stages [5]. In a first stage, we take into consideration all the manners of disposing the constitutive structure elements of a biomacromolecule within a given volume.

From the many possible conformations, only those are selected, in the second stage, that yield a uniform disposition of the entities within the available volume.

The last and decisive stage of an optimal modelling in the case of a biomacromolecule admitting of three preferential typical parameters for two conformations must result in a suitable matrix and at the same time in a mathematical model useful for programming the electronic computers [6]. The stereoregular distribution of the amino-acid residues in the polypeptide chains or in the order state of the ribonucleic acid macrochains, with secondary or tertiary structure can supply conformational types liable to be modelled in the above-mentioned conditions [7].

In some cases, the reduction of the number of conformations and of characteristic parameters of the modelled biomacromolecule can be obtained so that the global matrix lead, by suppressing the state of absurd interdependence of its elements, to a reduced matrix. This reduced standard base afford to make use of a logico-mathematical formalism by which the use of a computer can be spared within the limits of the comparison between the constructed model and the actual biomacromolecular system. The conformations and the parameters constituting the elements of the reduced matrix have to reflect the essential physical, chemical and structural peculiarities of the biopolymer.

A PECULIAR MATHEMATICAL MODEL

A particular interest is offered by the mathematical formulation of the selection problem of a biomacromolecular model concomitantly and restrictively characterized by two conformations and three parameters.

The Q_i , ($i = 1, 2$) conformations and the P_j , ($j = 1, 2, 3$) essential parameters are considered which describe some state or another of the given biomacromolecule. According to a usual convention, the presence and the absence of a characteristic element in the matrix is noted by 1, respectively by 0

The total number of the possible combinations of elements liable to describe an actual physical state or an absurd state, either by the absence of the conformations, or by the non-correspondence of the parameters with the given conformations, is equal to the number of the element columns in the global matrix, namely:

$$N = 2^{2+3}$$

In the particular case of the matrix hereafter, $N = 32$, while the number of the elements disposed according to evident rules is 160:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Q_1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q_2	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
P_1	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0
P_2	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0
P_3	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

It is to be remarked, for instance, that the first column, considered as a set of elements describing a probable state of the modelled biopolymer, points out the presence of both the Q_1 conformation and the Q_2 conformation, as well as the probability for both of them to be restrictively characterized by the three parameters P_1 , P_2 and P_3 . For a statistical system of types Q_1 and Q_2 conformers, set 1 is illustrative, while admitting, at the same time, that parameters P_1 and P_3 characterize conformation Q_1 and P_2 characterizes only conformation Q_2 . With these restrictions imposed, as rule, by experiments, set 1 becomes inconsistent with the state of one or another of the two conformers, individually considered.

A biomacromolecule admitting of only one conformation, e.g. Q_1 , cannot be described according to the above-mentioned restrictions, except by parameters P_1 and P_3 . In the given matrix, to this state corresponds set 11.

To conformation Q_2 , described by essential parameter P_2 , is associated, according to the same restrictions, the set of elements bearing number 22.

All conformations of elements in sets 25—32 become physically inconsistent as a result of the absence of both conformers in the system under consideration.

Set 3 is assimilated to set 11, since it expresses completely the same state of conformer Q_2 . In this set, the absence of parameter P_2 , makes inoperative the presence of conformer Q_2 .

These are, chiefly, the criteria of selecting combinations or of eliminating the sets inconsistent with macroscopic states of the biopolymer system admitting of a given modeling.

In terms and expressions of the symbolistic logic applicable to this particular mathematic model, the qualitative theory of the above mentioned selection criteria consists in the following propositions:

1. $Q_1 \rightarrow P_1 P_3$;
2. $Q_2 \rightarrow P_2$;
3. $Q_1 Q_2 \rightarrow P_1 P_2 P_3$;
4. $Q_1 \bar{Q}_2 \rightarrow [P_1 P_3 (-P_2)]$;
5. $\bar{Q}_1 Q_2 \rightarrow [(-P_1) P_2 P_3]$;
6. $\bar{Q}_1 \bar{Q}_2 \rightarrow [P_1 P_2 (-P_3)]$;
7. $\bar{Q}_1 \bar{Q}_2 \rightarrow [(-P_1) (-P_2) P_3]$;
8. $\bar{Q}_1 \bar{Q}_2 \rightarrow [P_1 (-P_2) (-P_3)]$;
9. $\bar{Q}_1 \bar{Q}_2 \rightarrow [(-P_1) (-P_2) (-P_3)]$.

Thus, proposition 5, in the respective transcription, shows that though both conformers exist in the system, conformation Q_1 cannot be taken into consideration, since its physical state cannot be completely described, owing to the absence of parameter P_1 .

The interdependence of the elements concurring in globally expressing the state of the system as described by propositions 1–9, can be represented in the form of a function:

$$F = F(Q_1, Q_2; P_1, P_2, P_3)$$

which, expressed in a form suitable to the constructed model should lead to the reduced matrix.

This matrix is subordinate to the logical set of propositions and is consistent with the physico-chemical data of the modelled biopolymer system.

CONCLUSIONS

The confrontation of the physical model of a biomacromolecular system with its mathematical model, through the agency of the reduced matrix, constitutes a conclusive way for bringing into relief the correlation existing between the parameters and the conformations that they describe with priority and selectivity. The particular method and model permit, within the above-mentioned logical limits, the efficient survey of some biopolymer systems simply characterized by two conformations and three essential parameters.

In the case of aqueous solutions of biopolymers, conformations helix and coil can be taken into consideration as well as the parameters illustrating the solubility, the hydrophilia and hydrophobia of the macromolecular constituents

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DETERMINATION OF IONISATION ENERGY OF IN CDSE THIN LAYERS

V. RUXANDRA and G. TOPLICEANU

ABSTRACT

In this work is given results obtained on the determination of the ionisation energy of donors in activated and unactivated CdSe thin layers, on the basis of the temperature variation of conductivity.

1. INTRODUCTION

The wide field of applications in microelectronics, fotodetectors and solar piles construction, etc., has determined amply researches on the photo-sensitive thin films of A^{II} B^{VI} compounds [1] — [3]. Due to the strong dependence of the results on the „history“ of the sample previous to correlate the results obtained by different workers.

Moreover, the explanation of the photoconduction properties of samples obtained under definite conditions requires the concrete knowledge of conduction properties.

In this work we should expose the results of the determination, through temperature variation of conductivity, of donor ionisation energies in activated and unactivated CdSe thin films.

2. GENERAL CONSIDERATIONS

The procedure we have use in order to obtain the thin films has favoured the formation of Se vacancies. On the other hand the irreversible growing of resistivity of CdSe films after to their preparation, probably caused by oxygen absorbtion [4,5] leads to the hipotesis that even at low temperatures part of the donors are ionised and we may thus consider the samples as compensated semiconductors.

Because this change of conductivity is about 2—4 orders of magnitude the compensation is strong enough to enable us to express the conductivity σ (temperature change of the Fermi level is small) through relations of the form:

$$\sigma = \sigma_0 \exp\left(-\frac{E_d}{kT}\right) \quad (1)$$

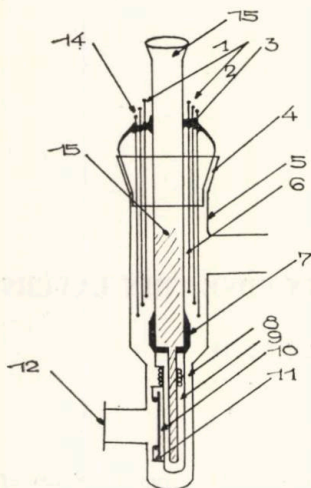


Fig. 1. Schematic diagram of experimental apparatus for measuring conductivity as a function of temperature;

- 1, 2. electrical leads
3. glass — metal joint
4. glass — glass joint
- 5, 6. glass tube
7. glass-copper joint
8. heater wires
9. copper cylinder
10. samples
11. socket for mounted thin films
12. quartz optical window
13. liquid nitrogen
14. thermocouple leads
15. funnel

In the $(100-200)^{\circ}\text{K}$ range, the $\lg \sigma = f(1/T)$ function is linear and its average slope leads to an ionisation energy $E_d = (0,15 \pm 0,005) \text{ eV}$.

For activated samples of the same series, the results corresponding to different degrees of activation are represented in fig. 3. The samples activated in mixtures of $\sim 10^{-2}$ torr pressure show conductivity variation with temperature reverse that, at low temperatures, has a slow increase, followed by a marked increase in the intermediary temperatures range and a weak saturation tendency at temperatures around and above the environment temperature (see curves 1, 2, 3).

The samples activated at mixture pressure values around the value of the atmospheric pressure show low conductivity variations with temperature reverse, with a saturation tendency from temperatures of about 200°K (see curves 4, 5, 6).

For activations at intermediary mixture pressure the conductivity variation with temperature reverse, curve are contained between the two

where, E_d is the donor ionisation energy, measured at the lower edge of the conduction band, k is Boltzman's constant, T is the temperature in Kelvin degrees and σ_0 , can be considered as a constant since for low temperatures the predominating scattering mechanism on $\text{A}^{IV}\text{B}^{VI}$ compounds is the scattering by lattice vibrations. The situation is generally the same for activated samples, the activation only increases the compensation.

3. EXPERIMENTAL ARRANGEMENT

The preparation and the electric, structure and photoconduction specific features of the samples were detailed in [6,7].

Here we wish only to specify that in these experiments were used layers activated in (air-Cl) mixture under the conditions that were shown in [6], [7] except the pression that was varried between 760 and 10^{-2} torr. The samples were placed in a cryostat fig. 1 — build in our laboratory this permitted to vary the temperature continuously between 100 and 360 Kelvin degrees. The temperature was measured with a Copper — Constantan thermocouple with preission of $0,5^{\circ}\text{K}$.

4. EXPERIMENTAL RESULTS-DISCUSSION

For a few unactivated CdSe samples the conductivity variation with the reverse of the temperature is plotted in fig. 2.

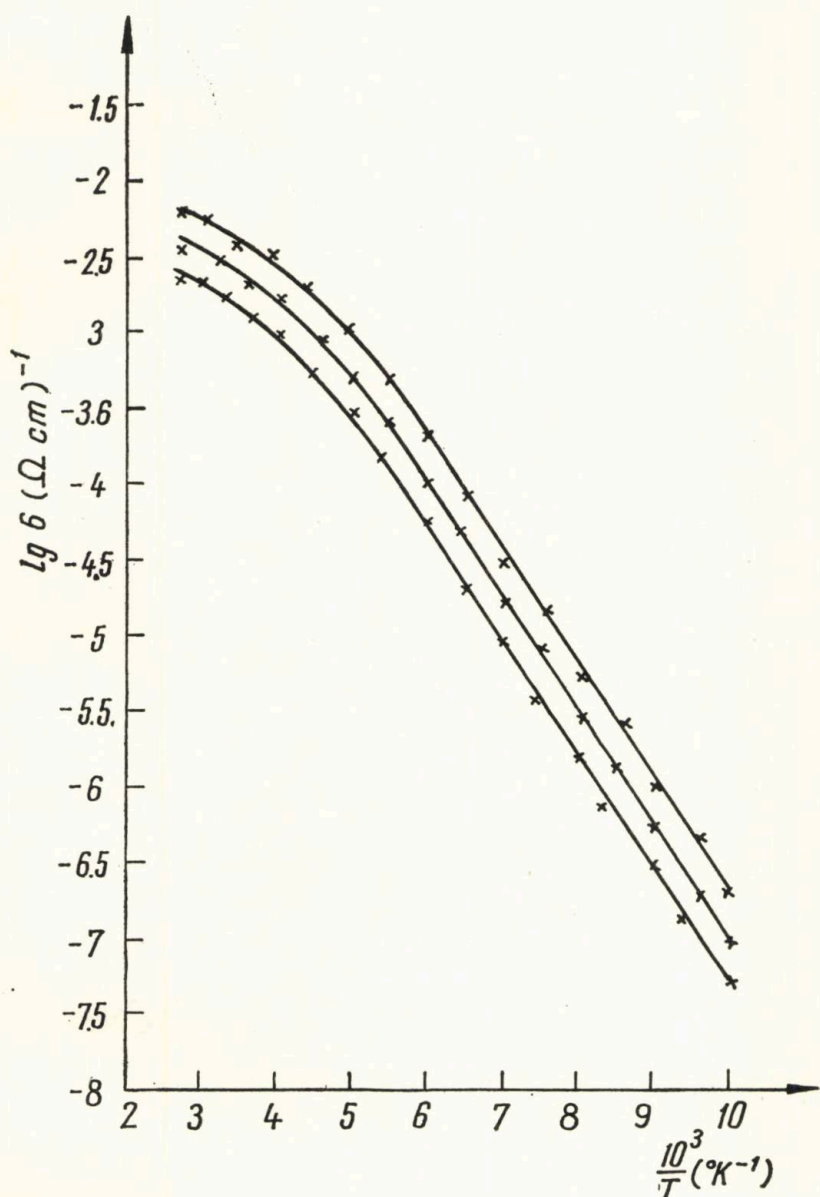


Fig. 2. Conductivity as a function of temperature for unactivated CdSe thin layers.

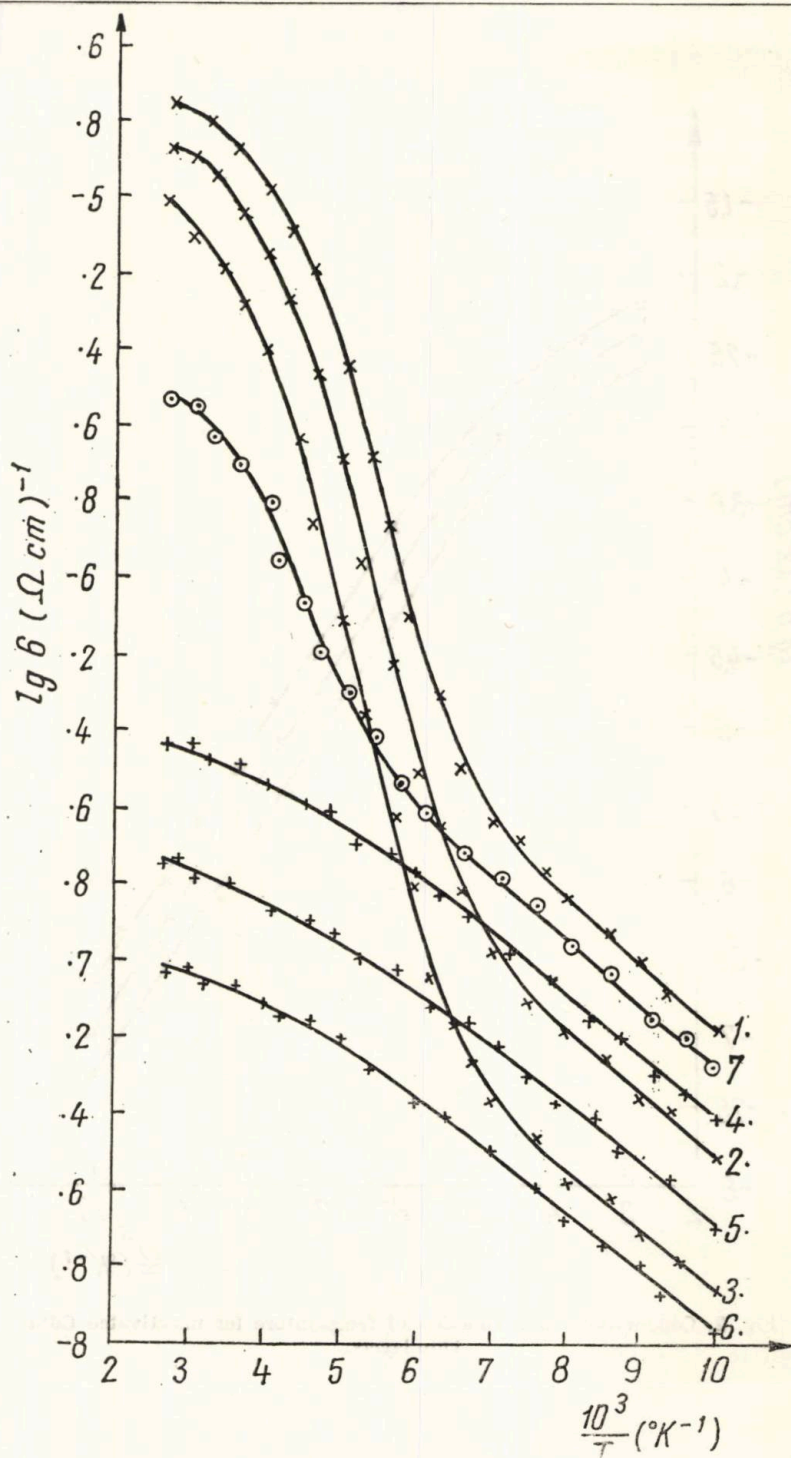


Fig. 3 Conductivity as a function of temperature for activated CdSe thin layers.

extreme above mentioned situations, with the particularity that the marked increase portion slowly disappears as the mixture pressure increases, being nearly absent for activations in 10–50 torr pressure mixtures.

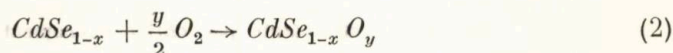
On the fig. 3 curve 7 shows the conductivity variation with temperature reverse for a sample activated in an 0,5 torr pressure mixtures.

At low temperatures, the $\lg \sigma = f(1/T)$ functions are linear for all samples, the straight lines have approximately the same slope and the mean value of these leads to an ionisation energy $E_{ai} = (0,035 \pm 0,003) \text{ eV}$. At intermediary temperatures samples like those numbered 1, 2, 3 show also a linear dependence of the $\lg \sigma = f(1/T)$ functions, average slope of the straight lines leading to a different ionisation energy, namely $E_{aII} = (0,15 \pm 0,005) \text{ eV}$.

The results obtained for unactivated CdSe samples agree with their preparation way and with the results obtained by other workers so CdSe mono-crystals [8], the energy level at 0,15 eV under the lower edge of the conduction band corresponds to Se vacancies.

For activated samples the level at 0,035 eV under the lower edge of the conduction band it is probably to correspond to chlorine impurities (though it is very difficult to find an energetic explanation of the successive manifestation of these two levels).

Existence of the second level at 0,15 eV under the lower edge of the conduction band and fact that this level appears only in samples activated in low pressure mixtures leads us to suppose that in these samples the reaction



is not complete, that y differs from x with such an amount that after activation there exists a considerable Se vacancies concentration. We therefore assign the second level that exists in activated samples of the kind of those marked 1, 2, 3 to Se vacancies.

To close up we stress the fact that the lowering of activation mixture pressure from 760 to 10^{-2} torr does not affect the photosensitivity by more than a 10–15 factor.

From the structural point of view we observed a higher hexagonal phase weight in samples in which the reaction (2) is approaches complete on the contrary in samples activated at low mixture pressures the cubic phase predominates.

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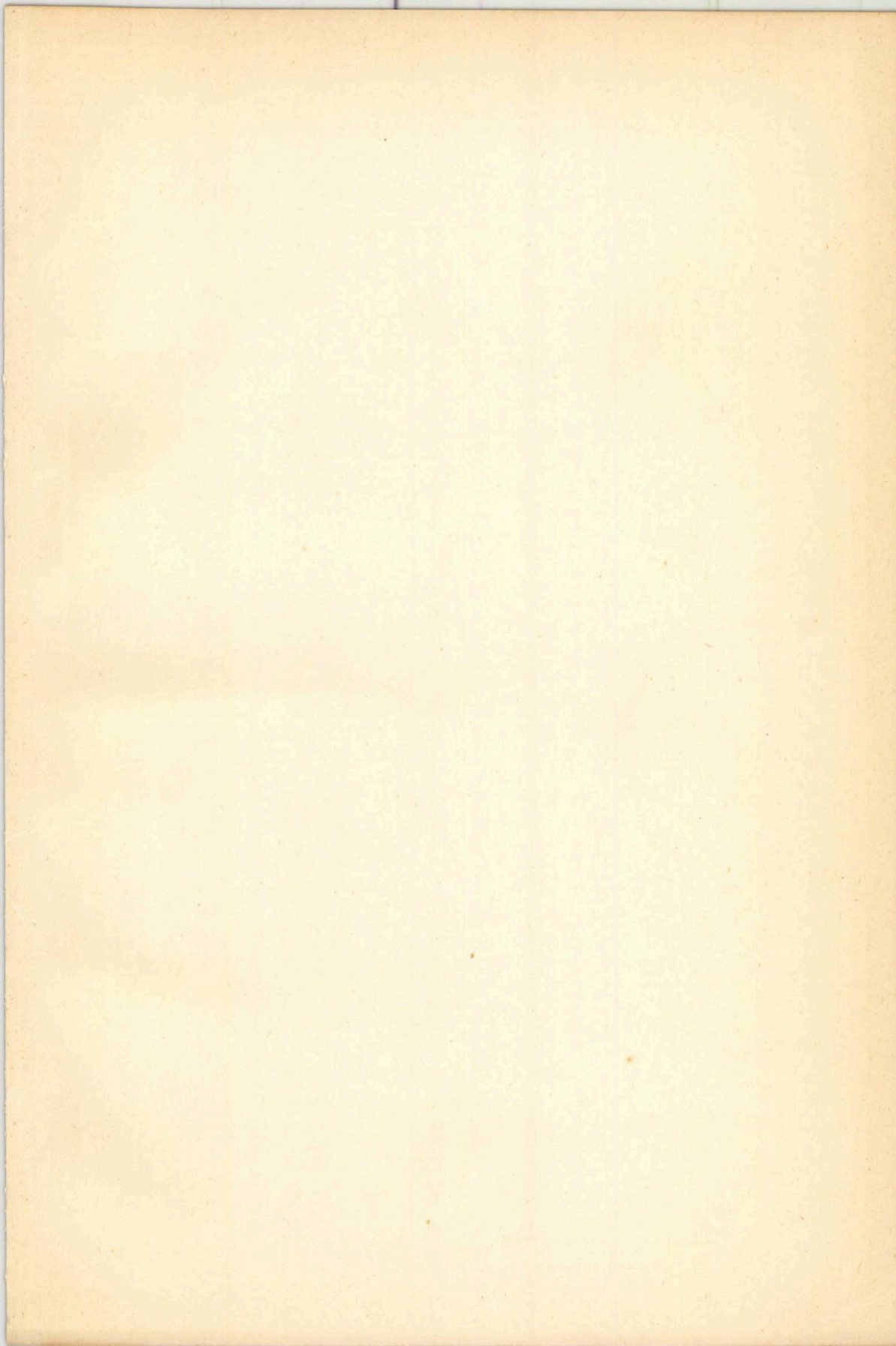
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